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WADC TECHNICAL NOTE 57-392

ACOUSTICAL EVALUATION OF TWO DURASTACK GROUND RUN-UP NOISE SUPPRESSORS

NORMAN DOELLING

AND

THE STAFF OF BOLT BERANEK AND NEWMAN INC.

NOVEMBER 1961

CONTRACT No. AF 33(616)-3335

NOX

BIOMEDICAL LABORATORY
AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

WADC TN 57-392

Bolt Beranek and Newman, Inc., Cambridge, Massachusetts
ACOUSTICAL EVALUATION OF TWO DURA-STACK GROUND RUN-UP NOISE SUPPRESSORS, by Norman Doelling. November 1961. 49p. incl. illus. 1 ref. (Proj. 7210; Task 71708) Unclassified report

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900 - April 1962 - 26-1080 & 1081

FOREWORD

This report was prepared by Bolt Beranek and Newman Inc., Cambridge, Massachusetts, under Contract AF 33(616)-3335, for the Aerospace Medical Laboratory, Aeronautical Systems Division, in support of Project 7210, "Human Response to Vibratory Energy," Task 71708, "Investigation of Physical Structures and Their Components with Respect to Their Characteristics for Acoustic Energy Reception, Transmission, and Reduction." Mr. R. N. Hancock was the task engineer. Technical supervision of the preparation of this report was the responsibility of Mr. K. M. Eldred, Mr. R.N. Hancock, and Dr. H.E. vonGierke, Bioacoustics Branch, Biomedical Laboratory, Aerospace Medical Laboratory. Personnel participating in the survey from Bolt Beranek and Newman Inc. were: Mr. N. Doelling, Mr. W. H. Pickett, and Mr. K. Pearsons. Mr. Roland C. Bergh of Republic Aviation Corporation directed operation of the aircraft and Mr. Stannard Potter of Industrial Acoustic Company observed the measurements.

ABSTRACT

Measurements of the noise characteristics of two "Durastack" noise suppressor systems are reported. The only difference in the two systems is the acoustical treatment of the secondary air intake. Type A suppressor has essentially no acoustical treatment in the secondary air intake while Type B is acoustically treated. Measurements in octave bands taken on a 250-foot circle and at close-in positions are presented. Average noise reduction of both types of suppressors is fairly flat above the first octave band. The average value of the noise reduction from 75 to 10,000 cps is about 14 db for the Type A noise suppressor and about 21 db for the Type B noise suppressor. No intake suppressor was used. The relative magnitude of the major noise sources of the aircraft suppressor is also presented. Some non-acoustical aspects of the noise suppressors are included in the appendix.

PUBLICATION REVIEW

Jos M Quashnock

JOS. M. QUASHNOCK
Colonel, USAF, MC
Chief, Biomedical Laboratory
Aerospace Medical Laboratory

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INTRODUCTION

A. General

As part of a broad program sponsored by WADC for the purpose of gathering information on the acoustical effectiveness of aircraft noise suppressors, measurements were carried out on two Durastack* ground run-up noise suppressors for F84F and RF84F aircraft. These measurements were obtained during noise surveys in May and June 1956 at Republic Aviation Corporation, Farmingdale, Long Island, New York. A prototype suppressor (designated as Type A in this report) was the subject of the May survey, and a final model of the suppressor (Type B) was evaluated during the June noise survey.

The acoustical effectiveness of each noise suppressor system was determined during these surveys by means of the insertion loss method. To determine the insertion loss provided by a noise suppressor system, measurements of sound pressure level (SPL)** are made at a given position with and without a noise suppressor attached to the aircraft. The difference between the measured values of SPL is defined as the noise reduction afforded by the noise suppressor at the given position.

During each survey two sets of insertion loss measurements were made. Measurements of SPL were made as a continuous function of position on a 250-foot circle centered at the exhaust orifice of the aircraft to determine the noise reduction characteristics in the distant (far) field. Measurements of SPL were also made at several positions close to the aircraft (herein referred to as "close-in measurements") in order to determine the noise reduction characteristics in the area where maintenance personnel may be present during operation of the aircraft.

In addition to the insertion loss measurements, additional acoustical measurements were made in an attempt to determine the contributions to the average SPL's at 250 feet of the three major noise sources of the suppressed aircraft:

1) Primary air intake
2) Exhaust of the noise suppressor
3) Secondary or cooling air intake

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*Manufactured by the Industrial Acoustics Company, Inc., 341 Jackson Avenue, New York, New York.

**$SPL = 20 \log \frac{P}{2 \times 10^{-4}}$, where P is the sound pressure in μ bar.

B. Description of the Two Noise Suppressors

Most exhaust ground run-up noise suppressors consist of three components. One component is an acoustic treatment whose function is to attenuate the acoustical energy propagated through it. A second component is an eductor or augmenter tube whose function is to direct the jet engine exhaust stream into the noise suppressor and to provide a region for mixing of the combusted exhaust gases of the jet engine with the secondary cooling air. A third component is the coupling between the eductor tube and the aircraft. Since the acoustical effectiveness of a ground run-up noise suppressor is not uniquely related to the acoustical characteristics of the acoustic treatment alone, it is necessary to make a clear distinction between the acoustic treatment and the noise suppressor. The two ground run-up noise suppressors which are the subject of this report used the same acoustic treatment and eductor tube. The two systems are distinguished only by different couplings between the aircraft and the eductor tube.

Both noise suppressors were designed and engineered as a joint effort of Industrial Acoustics Corporation, and Roland C. Bergh and members of his staff at Republic Aviation Corporation. Mr. Bergh and his staff concentrated their efforts primarily on the coupling and tie-down systems.

The unit cost of the noise suppressors is of the order of $30,000. The cost of the Type B system is estimated to be about $2,500 more than the Type A system.

The Type A suppressor was accepted by Republic Aviation Corporation about 1 September 1955 and the Type B suppressor was accepted about 15 June 1956.

The acoustic treatment in these noise suppressors is "Durastack", a product of the Industrial Acoustics Company, Inc. "Durastack" is a reactive treatment of 1/4-inch steel plate and contains no dissipative acoustical materials. The acoustic treatment section is 22 feet long and has an inside diameter of 10 feet 7-1/2 inches when cool. The Durastack treatment occupies about 20 feet of the rear of this section; the forward two feet being an "expansion chamber" which is connected to the eductor tube. The eductor tube is 20 feet long and has a 5-foot inside diameter. The acoustic treatment and the eductor tube may be seen in Figure 1.

Both the eductor tube and the acoustic treatment are covered on the outside with about 2 inches of Fiberglas which in turn is faced with about 3/4 inches of asbestos plaster material held in place by wire mesh screen. On top of the wire mesh screen a mastic-type damping compound has been added. The covering keeps the outer surfaces of the noise suppressors cool so that they do not present a hazard to personnel. In addition, the covering dampens structural resonances and hence increases the transmission loss of the walls of the noise suppressors.

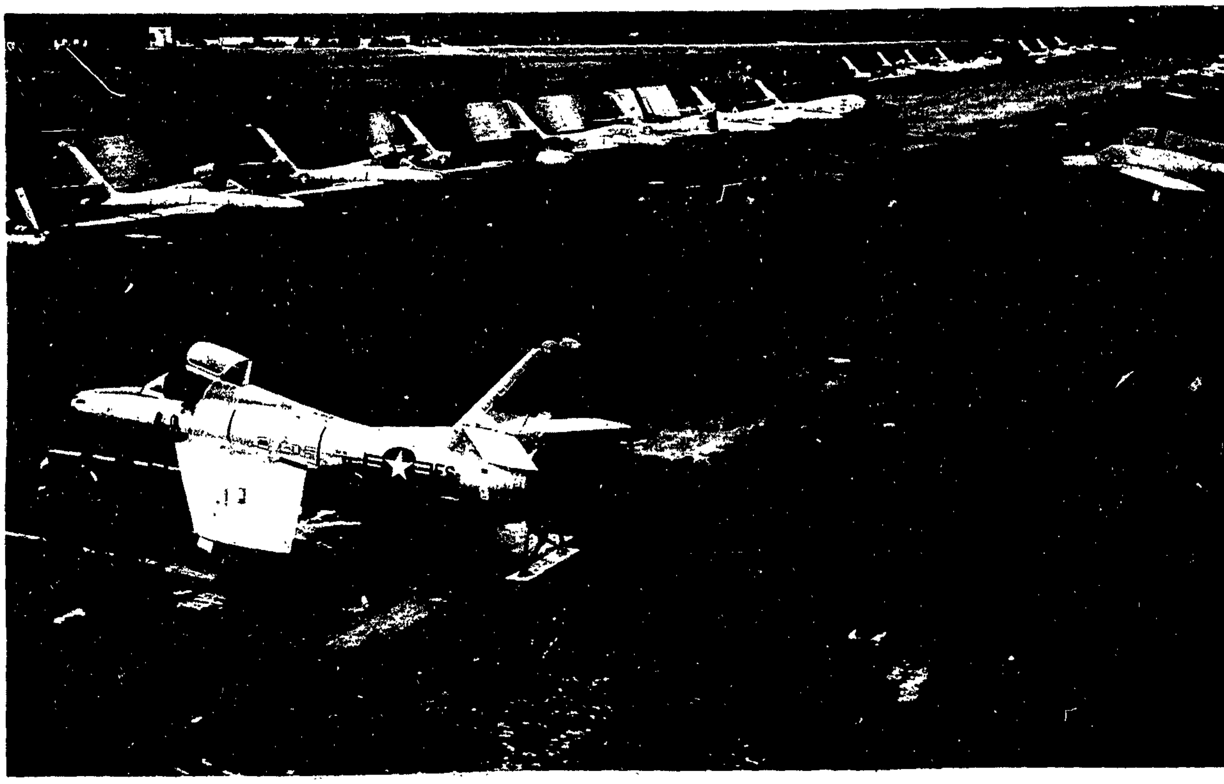


Figure 1. Durastack Ground Run-Up Noise Suppressor System

Figure 2 more clearly shows the coupling section and secondary air inlet used in what shall be referred to as the "Type A" noise suppressor. The coupling is cylindrical in shape, somewhat smaller than the eductor tube and spaced about 8 to 10 inches away from the aircraft as can be seen in Figure 2. This coupling is hinged to the eductor tube and both halves of the coupling swing open to allow coupling and decoupling of the aircraft to the noise suppressor. Closure of the coupling is accomplished by a screw device which is seen in Figure 2 at the bottom of the coupling. The inner surfaces of this coupling are lined with about 2 inches of Fiberglas which is covered with perforated sheet metal.

The coupling section used in the "Type B" noise suppressor is shown in Figure 3. This coupling is similar to the coupling of the "Type A" noise suppressor except that a 90° acoustically-lined bend is added to the secondary air inlet path. All interior surfaces of the coupling are also lined with 2 inches of Fiberglas faced with perforated sheet metal.

The method of positioning and stabilizing the aircraft relative to the coupling is discussed in some detail in Appendix I. Mr. Bergh of Republic Aviation Corporation has written a short memorandum on some aero-thermodynamic and acoustic design requirements and performance data of the Type B noise suppressor. This memorandum is included in Part 2 of Appendix I with his permission.

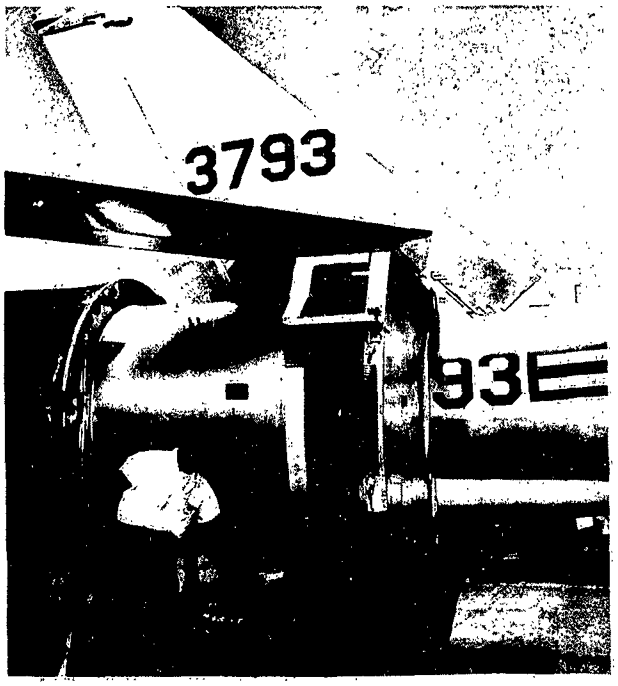


Figure 2. Coupling Section and Secondary Air Inlet Type A Noise Suppressor System

Figure 3. Coupling Section and Secondary Air Inlet Type B Noise Suppressor System

C. Measurement Site

The measurement site is a run-up strip which was previously part of a 200-foot wide runway. The noise suppressor and aircraft used in the test were located on the west side of this run-up strip. Figure 4 shows the position of the aircraft relative to the run-up strip as well as the 250-foot circles on which the distant field measurements were made. As can be seen in Figure 4, the blast fence on the east side of the run-up strip and two signboards shielded some parts of the measurement circles.

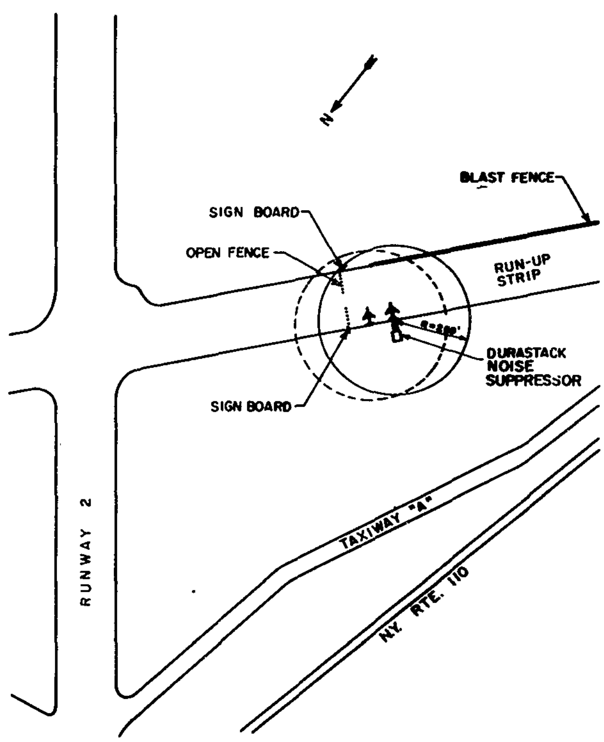


Figure 4. Measurement Site

SECTION II

MEASUREMENT AND DATA REDUCTION TECHNIQUES

A. Measurement Techniques

All acoustical data were recorded on magnetic tape using the twin-channel system illustrated diagrammatically in Figure 5. One channel of the tape recorder was connected with the data microphone (Altec 21BR-150 or Altec 21BR-200) which recorded the noise signal. The other channel of the tape recorder was connected to a "talk" microphone. The operator of the recorder simultaneously recorded attenuator settings, microphone positions and other significant data on the "talk" channel. Thus the recorded tape provides a complete record of the acoustical measurements.

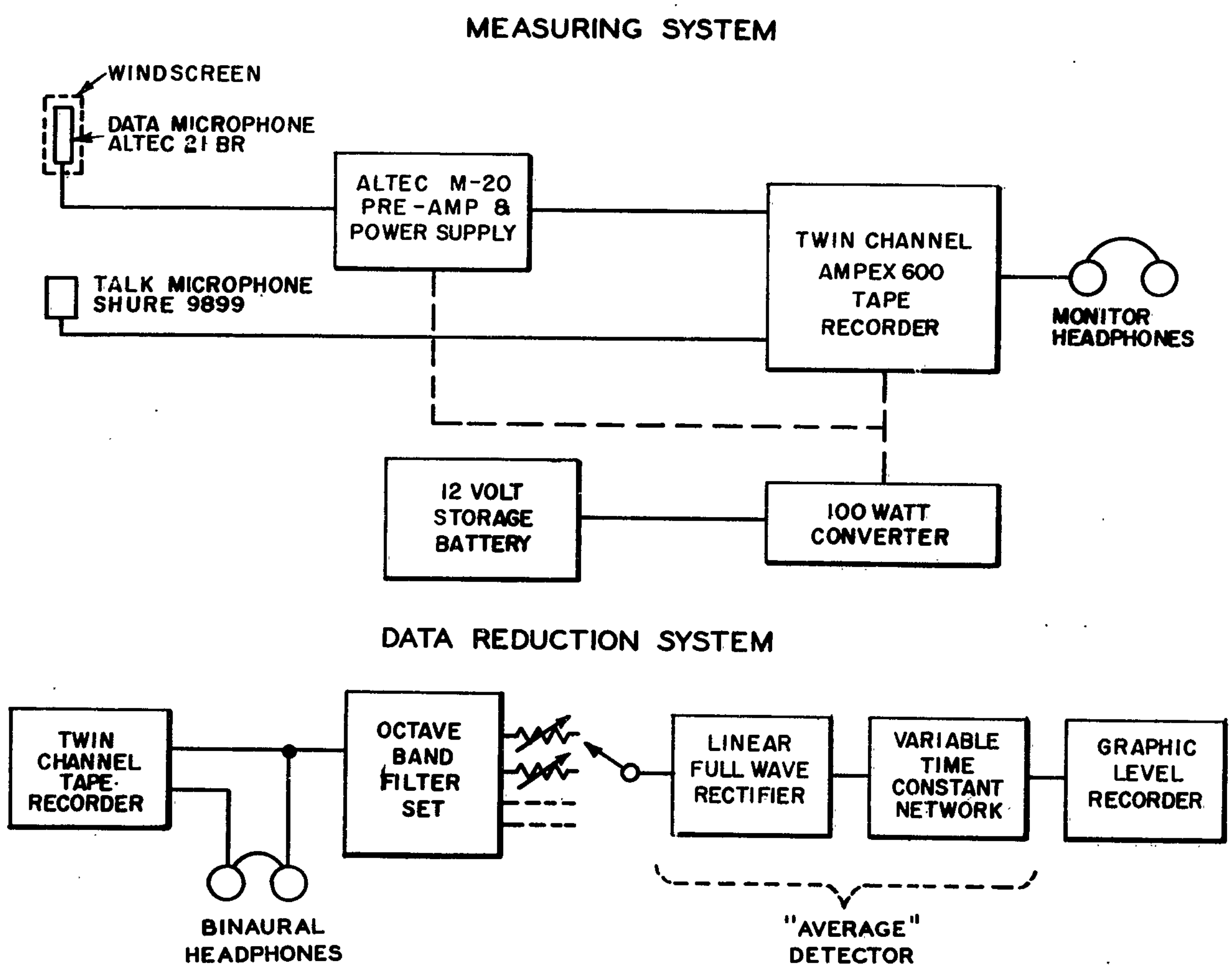


Figure 5. Measuring System and Data Reduction System

All of the equipment except the data microphone was located in, and operated from an automobile. Sixty cps electric power for the equipment was produced by a 12 volt vibrating reed converter which was connected to the storage battery of the car. The data microphone was hand-carried outside of the car and was connected to the recorder by a 50-foot length of low-capacitance cable. Care was taken at all times to keep the car at least 20 feet from the microphone, in a direction approximately normal to the direction of propagation of sound from the airplane to the microphone. Thus the presence of the car did not interfere with the noise field at the measuring position.

It should be noted that although the manufacturer and model are listed for all of the equipment components in Figure 4, essentially all of the major components have been modified to reduce temperature dependence, harmonic distortion, and microphonics, to improve frequency response and stability; and to increase the signal-to-noise ratio.

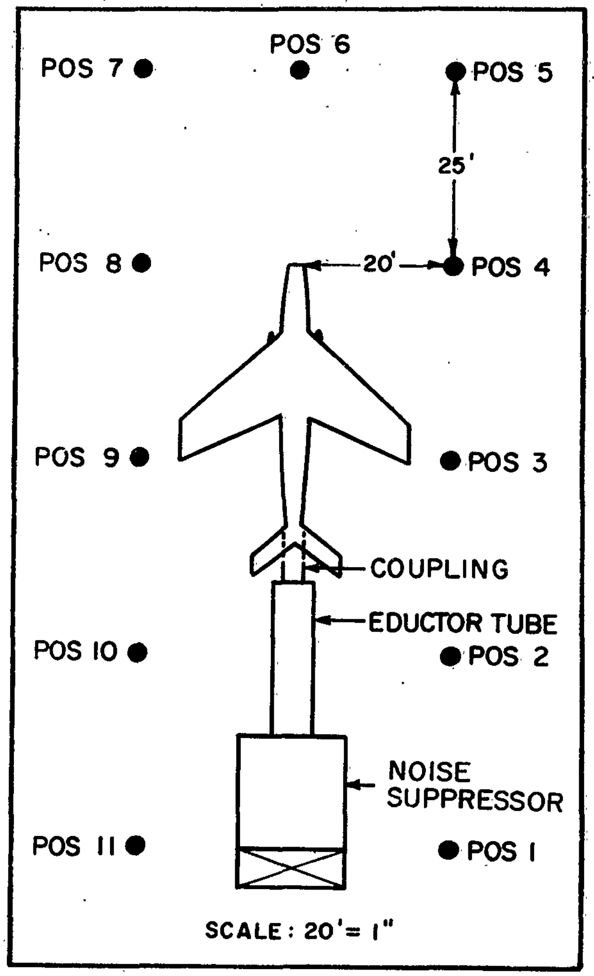
B. Data Reduction Techniques

Reduction of the data obtained during recording of SPL as a continuous function of position about the aircraft is accomplished by the system shown in Figure 5. An "average" detector, external to the graphic level recorder, is used in conjunction with a 60 cps chopper to reduce data on a level recorder.

This system is used since most graphic level recorders have peak detectors which are difficult to calibrate for use with random noise signals. Calibration is usually obtained by use of a 400 cps pure tone signal of known level, but if a pure tone, or even if a white noise of known average or rms level, is used to calibrate a peak detector, the calibration may not be valid for jet engine noise. The source of difficulty is that the response of a peak detector depends upon the time domain characteristics of the wave form under consideration rather than the average rms value of the signal. In view of the calibration difficulties, the external detector is used. The "quasi" dc output of this detector is chopped at a 60 cps rate and the chopped signal is used as an input to the level recorder. The input to the graphic level recorder is then always a square wave regardless of the wave-form of the input to the average detector. An added advantage of this system is that the frequency response of the graphic level recorder is no longer a significant variable to be considered in data reduction since the input is always a 60 cps square wave.

In using any type of detector, one is faced with a choice of the RC time constant involved. Since the average value of the jet noise taken over a short period of time (e.g., 0.1 second) varies considerably even at a fixed position from an engine which is operating at a fixed condition, it is desirable to have a long time constant in order to smooth the signal and to obtain a better approximation to the long-time average value of the rectified signal. However, if a very long time constant is used, then the output of the level recorder cannot change very rapidly (i.e., the output of the level recorder will not change significantly for a period of time approximately equal to the value of the time constant in seconds). This is obviously an undesirable situation since in the finite time required for a traverse about the airplane the average SPL will vary by about 20 to 25 db. Thus an engineering compromise must be effected between an attempt to obtain a good approximation to the long time average value of the signal and the necessity of having the recorder indicate the changes in level which occur in traversing about the aircraft.

In order to determine the time constant necessary to obtain a reasonable approximation to the long time average value of the signal, data recorded at a fixed position (measuring position 2; see Figure 6) near the suppressed aircraft were reduced using various time constants. It was found, in general, that for very short time constants, of the order of a hundredth or thousandth of a second, the value of the signal varied considerably as a function of time in any given octave band with the spread decreasing with increasing frequency. However, as the averaging time was increased, the spread in values of the signal decreased. It was found that a 1/2 second time constant would suffice to adequately smooth the signal obtained. This seemed to be a good compromise between having a short enough time constant which would follow changes in SPL as a function of position, and having a long enough time constant to adequately approximate the long time average of the signal. An 0.5 second time constant was used for the measurements made with the microphone in motion. A 1.0 second time constant was used for measurements made at fixed positions.



Close-In Measuring Positions

Figure 6.

SECTION III

NOISE REDUCTION OF THE SUPPRESSOR

As indicated in the introduction, the insertion loss method is used in determining the noise reduction characteristics of the Durastack noise suppressors. The noise reduction depends upon not only the geometry and/or materials used in the construction of the coupling, the eductor tube, and the acoustic treatment, but also upon several other parameters which are discussed below.

With a particular aircraft and engine attached to the noise suppressor, the noise field about the system will depend upon the relative magnitude and directional characteristics of the three major noise sources of the aircraft and noise suppressor: namely, the primary air intake, the secondary or cooling air inlet at the coupling, and the noise suppressor exhaust opening. Therefore, the noise reduction may vary with the operating condition of the engine, as well as with position (both azimuth and distance) and with frequency. Further, the relative level and directionality of the three sources mentioned above may vary if different aircraft and/or engines are used in conjunction with the noise suppressor. And thus, the noise reduction may also vary if different aircraft and/or engines are used.

Therefore, when noise reduction values are given for a particular noise suppressor, the following information must always be stated if the figures presented are to be meaningful.

1) The engine and aircraft used in conjunction with the noise suppressor.

2) The operating condition of the engine.

3) The position of the measurement (both azimuth and distance).

4) The frequency range of interest.

A. Noise Reduction at the Close-In Measuring Positions

The close-in measuring positions are shown in Figure 6. As can be seen, these positions form a 40-foot by 100-foot rectangle about the aircraft. One end of the rectangle is located 25 feet forward of the nose of the aircraft with the longer axis of symmetry of the rectangle being coincident with the longitudinal axis of the aircraft. During operation of the aircraft without the noise suppressor, measurements were made at Positions 2 through 10. With both the Type A and the Type B noise suppressors attached to the aircraft, measurements were made at Positions 1 through 11.

During the measurements on the Type A noise suppressor, the microphone was held about 5 feet above the ground at each position and a data sample from 15 to 30 seconds long was recorded. These data samples were reduced using an RC time constant of 1 second. When the Type B noise suppressor was being evaluated the measurements were made as a function of position about the measurement rectangle. These data were also reduced using an RC time constant of 0.5 seconds. It is found from comparison of the two methods of taking close-in data that the continuous method aids in locating "leaks", but that the fixed position method is generally adequate.

The measurements made during operation of the aircraft without the noise suppressor were made on the same day as the measurement on the Type A system. The measurements on the unsuppressed aircraft were not repeated when the measurements were made some two months later on the Type B noise suppressor. The stability of the J-65 engine as a noise source was verified by comparison of the far field unsuppressed data taken during each of the surveys. These data show that the variation in sound pressure levels was only about 1 or 2 db in most frequency bands.

In Figures 7 through 10 the data taken at the close-in measuring positions are presented in each of the eight octave bands of frequency. In each octave band, the data are presented as a function of position on the perimeter of the measurement rectangle. The data on either side of the airplane at corresponding symmetrical positions, such as Positions 1 and 11, or Positions 4 and 8, are plotted as a single point. In all cases the data taken at corresponding symmetrical positions were within 2 db of one another and in general were 1 db or less apart. The data obtained during use of both noise suppressors, as well as with no noise suppressor attached to the aircraft, are presented on each curve.

Certain generalizations can be made concerning these plots. It is noticed that without a noise suppressor attached, the highest SPL's exist to the rear of the exhaust orifice of the aircraft. The SPL's decrease as one moves forward toward the nose of the aircraft. The decrease in SPL as one moves forward increases with increasing frequency.

With the Type A noise suppressor attached, the SPL's in most octave bands are highest at Positions 3 and 9 which are near the coupling between the aircraft and the noise suppressor. As one moves to the rear (toward Position 1) from Position 3, the SPL's decrease from 5 to 20 db, the decrease increasing with frequency. However, as one moves forward toward the nose of the airplane from Position 3, the levels decrease only slightly. It would appear that at the close-in measuring positions the coupling is the major source of noise, that most of the acoustic power is radiated forward, and that only a much smaller fraction of the acoustic power is radiated to the rear. This directionality of propagation may well be anticipated from the geometry of the coupling.

With the Type B noise suppressor attached, maximum SPL's in many octave bands, exist at Positions 3 and 9. These positions are approximately opposite the secondary air inlet.

As one moves to the rear from Position 3, the SPL's decrease less than in the case of the Type A system. As one moves forward toward the nose of the airplane from Position 3, the levels decrease more than in the case of the Type A noise suppressor. The coupling again appears to be the major noise source at the close-in positions, but the direction of maximum propagation in the case of the Type B noise suppressor is more nearly in a direction normal to the longitudinal axis of the aircraft. This redirection of the acoustic power radiated, as well as an absolute decrease in SPL's at all positions, results in a significant decrease in SPL in areas where personnel may be working during operation of the aircraft.

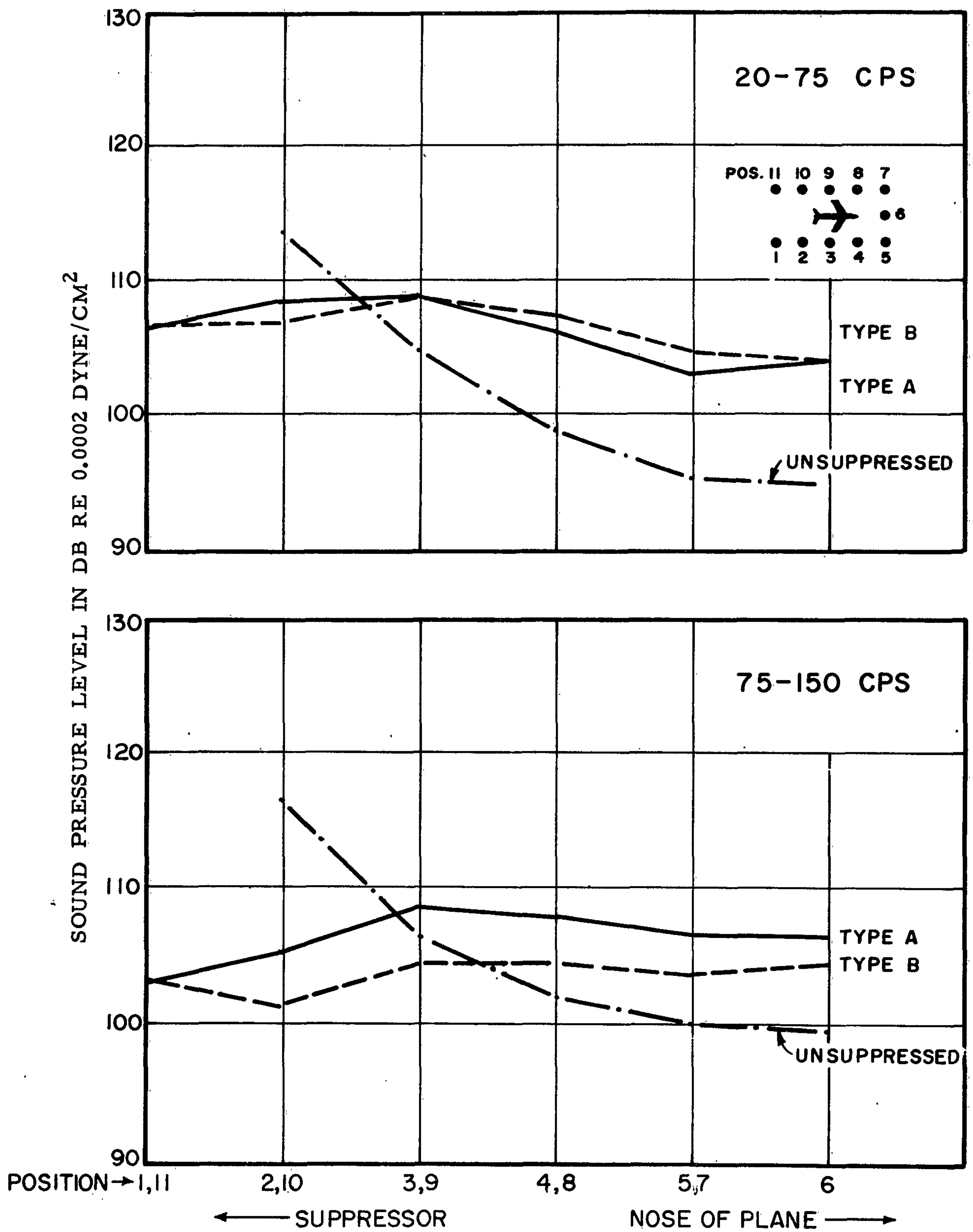


Figure 7. SPL on the Perimeter of the Measurement Rectangle; 20-75 CPS and 75-150 CPS (See Figure 6)

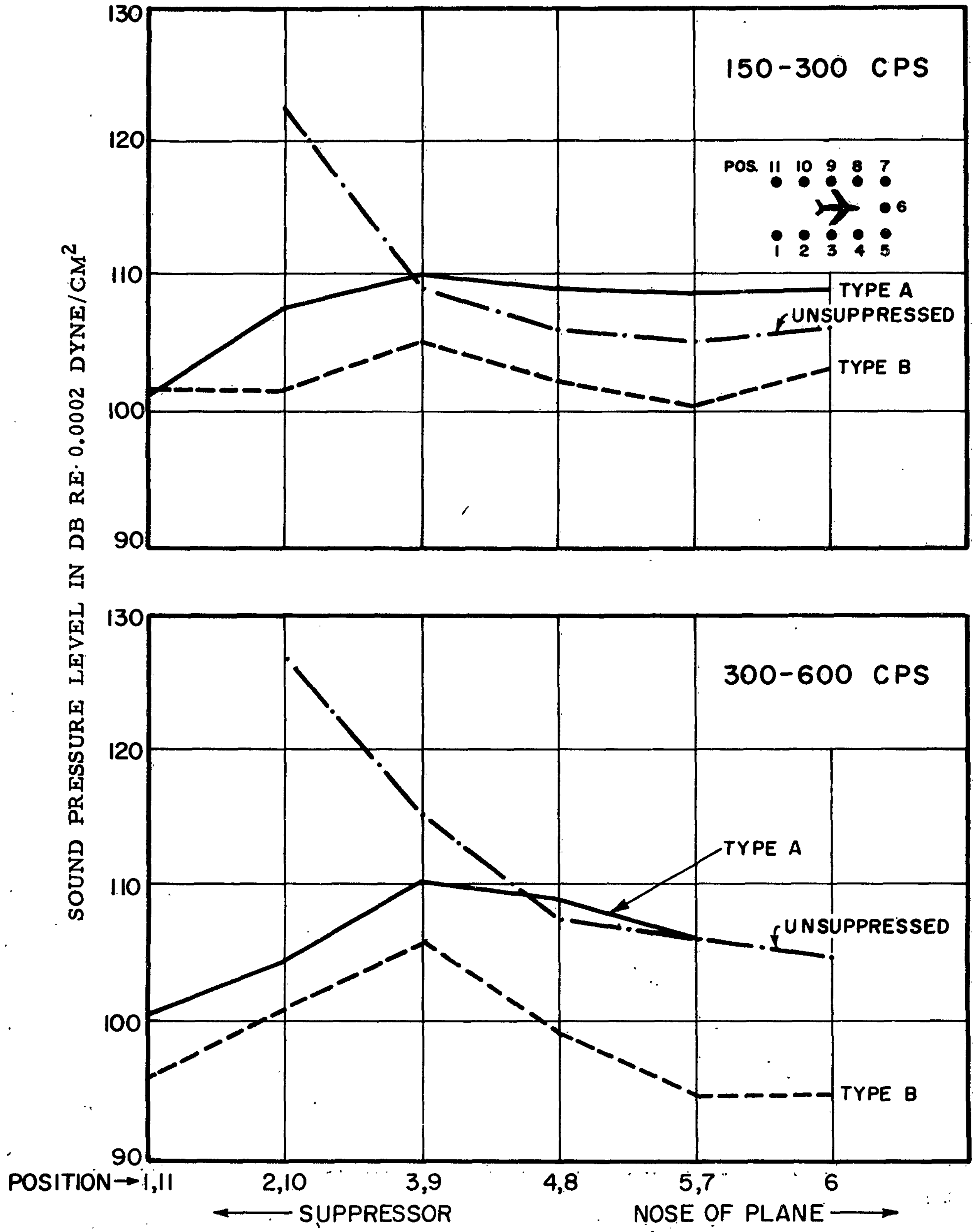


Figure 8. SPL on the Perimeter of the Measurement Rectangle; 150-300 CPS and 300-600 CPS (See Figure 6)

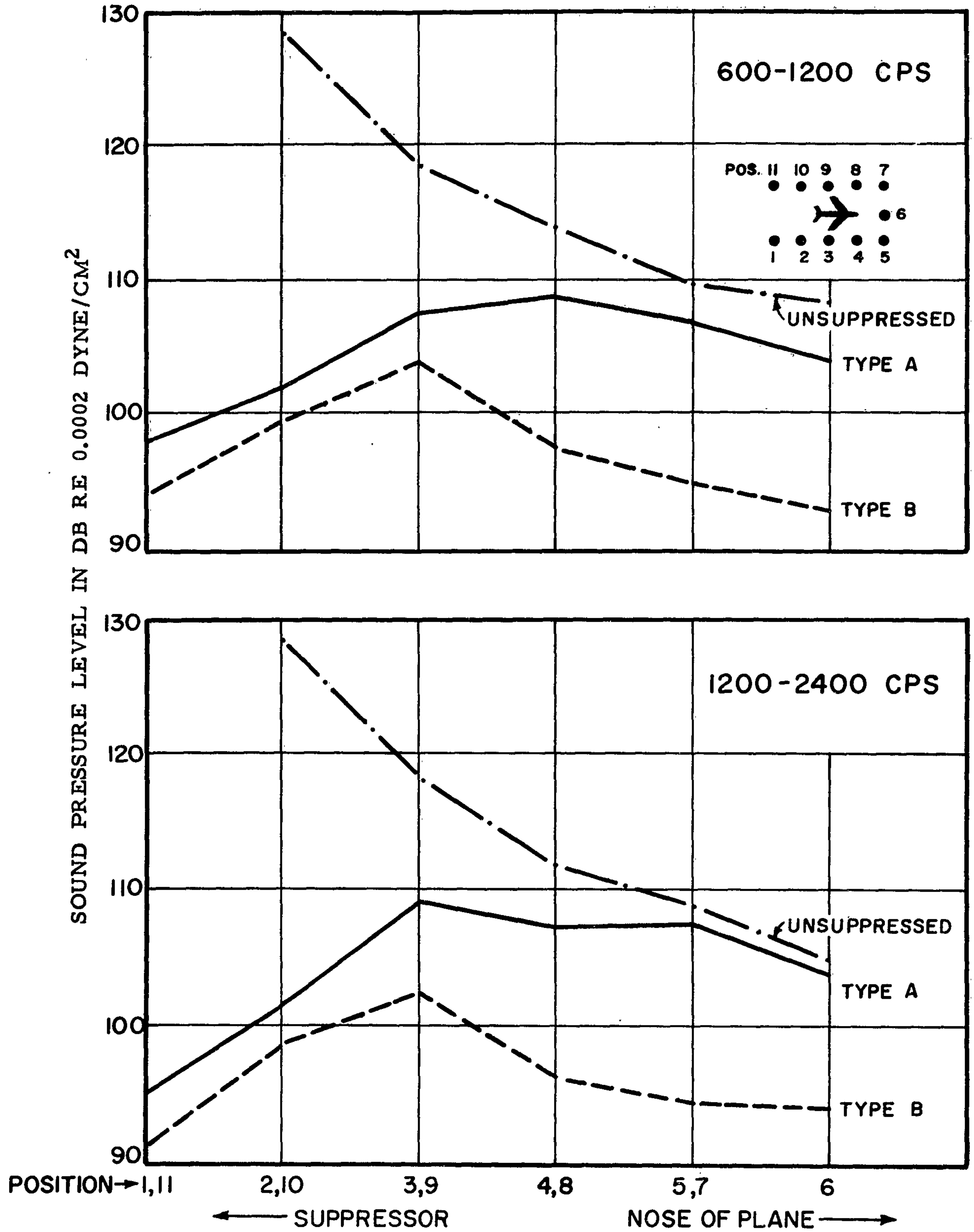


Figure 9. SPL on the Perimeter of the Measurement Rectangle; 600-1200 CPS and 1200-2400 CPS (See Figure 6)

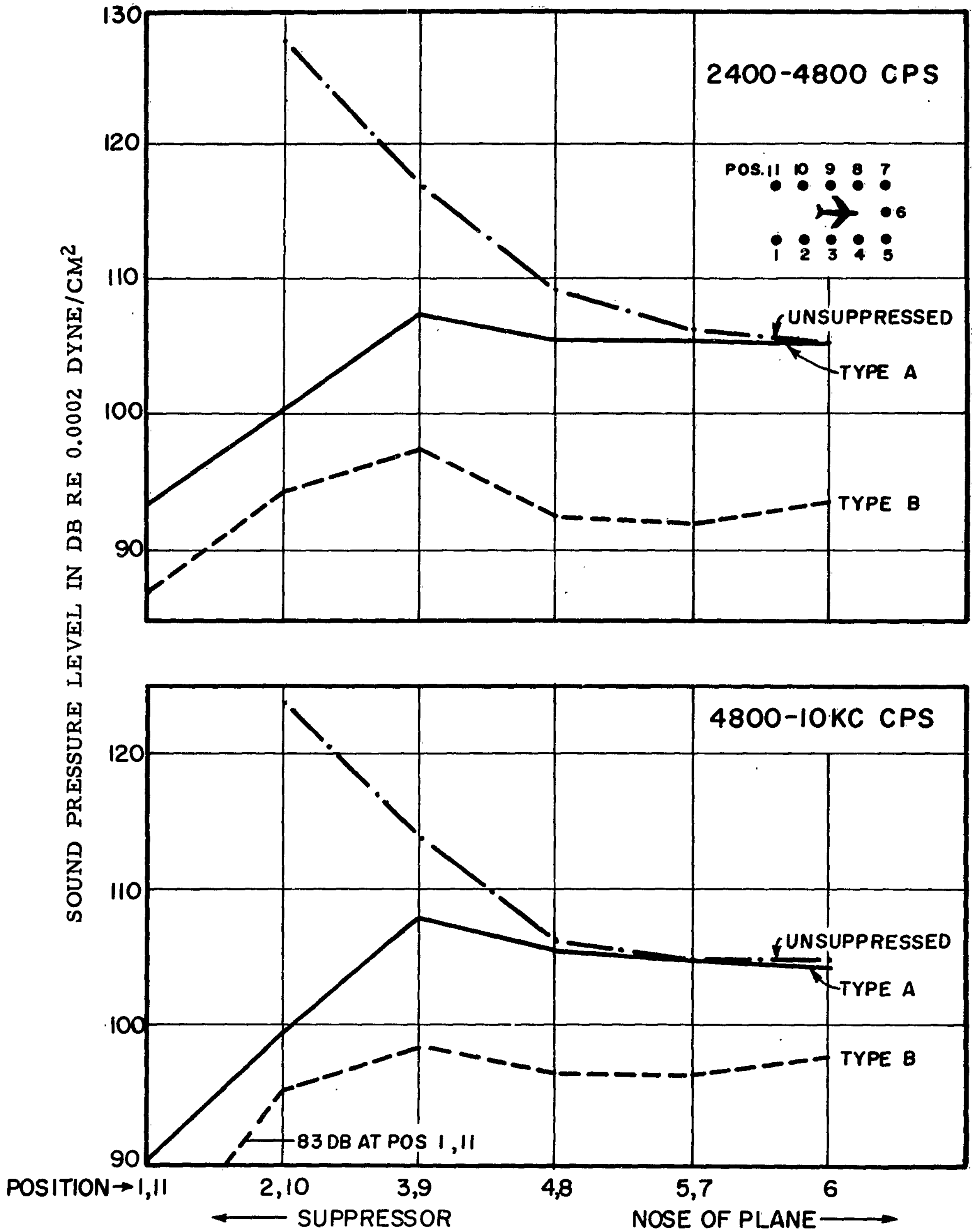


Figure 10. SPL on the Perimeter of the Measurement Rectangle; 2400-4800 CPS and 4800-10,000 CPS (See Figure 6)

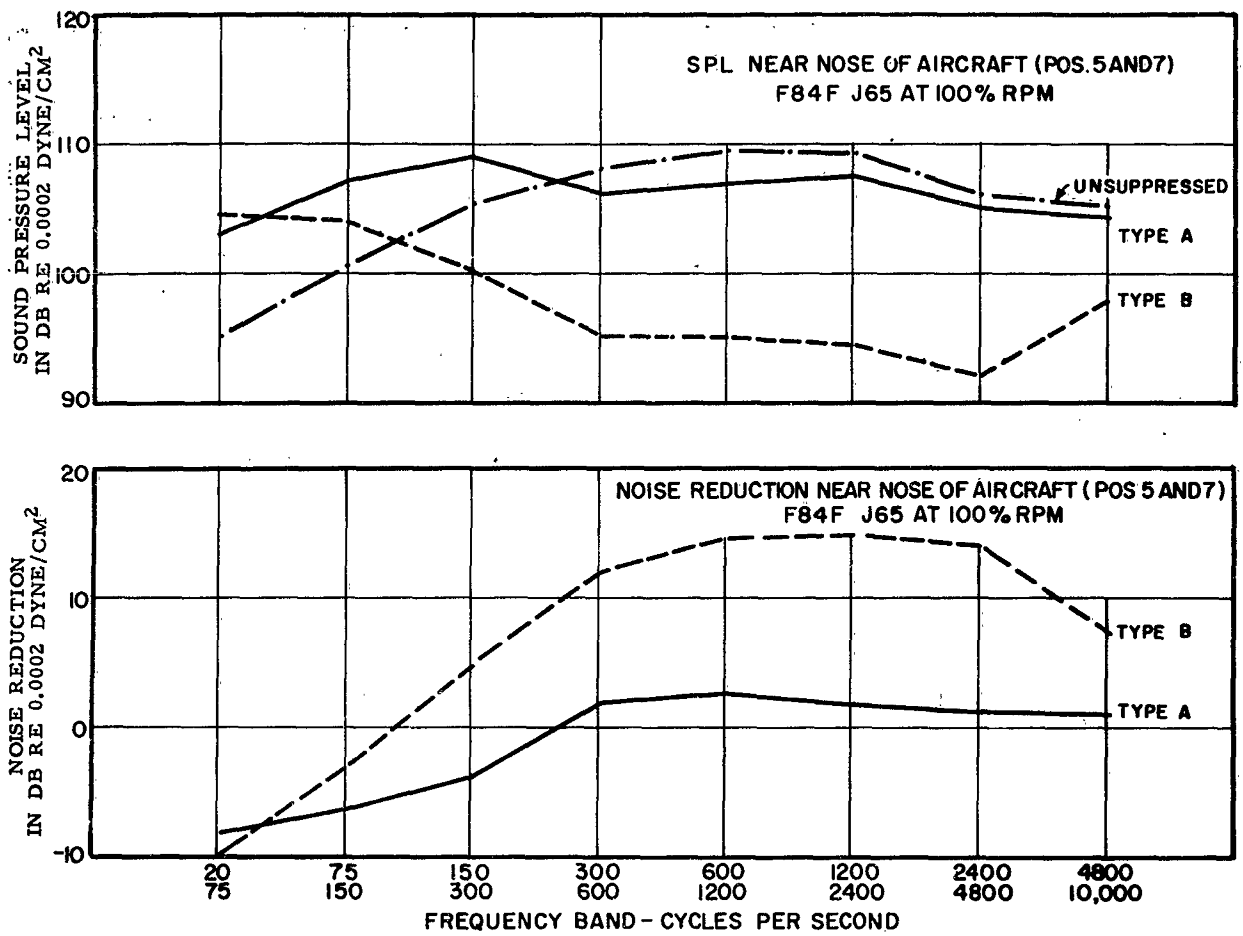


Figure 11. SPL near Nose of Aircraft

It is also of interest to study the spectrum of the noise produced at the different close-in measuring positions. The difference between the spectra at a given position with and without the noise suppressor attached, is a measure of the acoustical effectiveness of the noise suppressor at that position. The measured spectra at two of the close-in positions are presented in Figures 11 and 12. Again, data at symmetrical positions have been averaged and a single curve is presented for each pair of positions.

Figure 11 shows the SPL's and noise reduction in the vicinity of the nose of the aircraft (Positions 5 and 7) without a noise suppressor and with the Type A and Type B noise suppressors. As can be seen at these positions, the Type A noise suppressor is relatively ineffective in the first 3 octave bands (20-300 cps). The Type A noise suppressor actually increases the SPL's from 20 to 300 cps. Above 300 cps an attenuation of 1 or 2 db is obtained. The Type B noise suppressor also increases the SPL's in the first 2 octave bands, but provides greater attenuation above 150 cps. The amount of attenuation provided is about 5 db in the 150-300 cps octave band and about 15 db above 300 cps. The decrease in noise reduction in the 4800-10,000 cps octave band indicates the major source of noise is probably the siren action of the compressor.

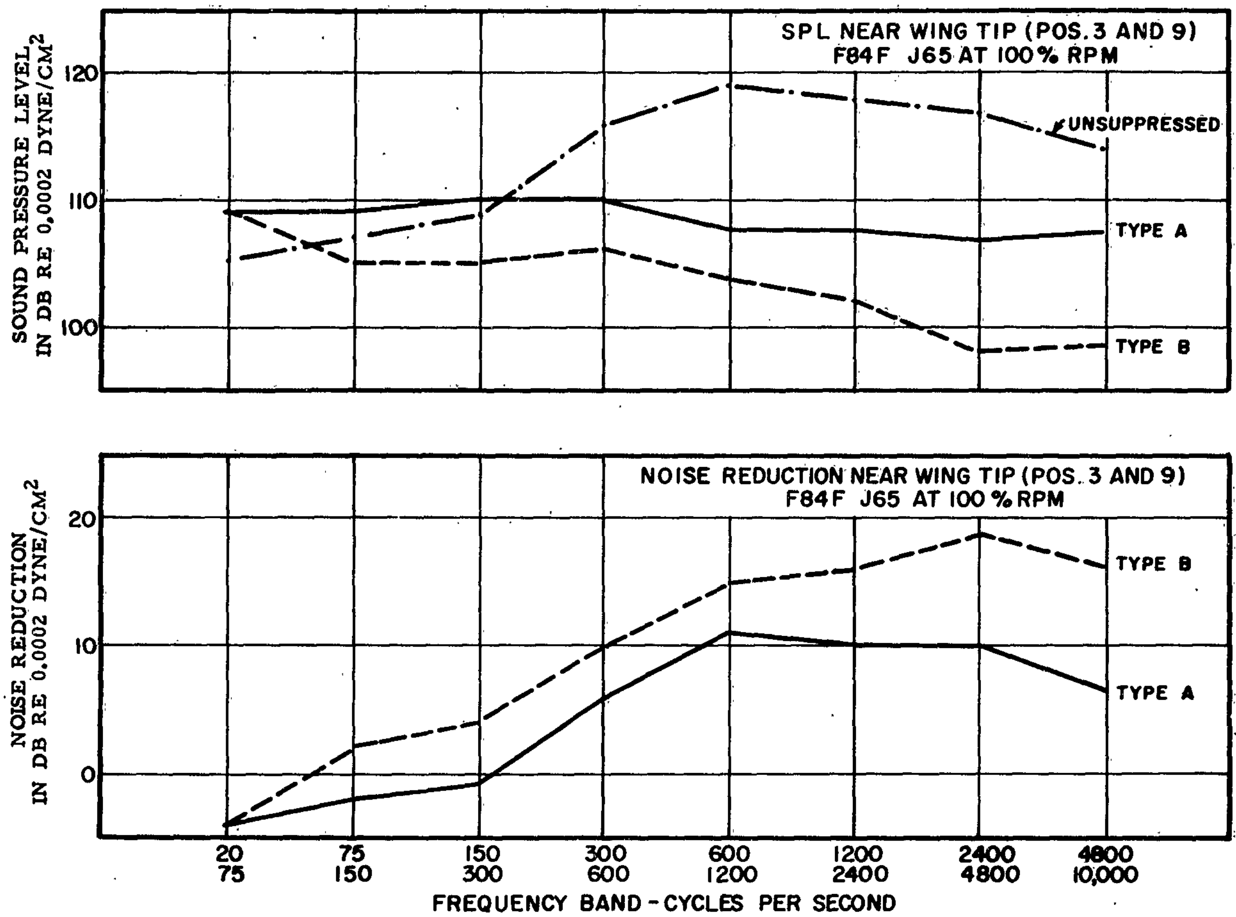


Figure 12. SPL near Wing Tip

In Figure 12 the SPL's and noise reduction near the wing-tip (Positions 3 and 9) are presented. The SPL without a noise suppressor attached is about 10 db greater here than at Positions 5 and 7 (see Figure 11). In this case, the Type A noise suppressor again affords an increase in SPL in the first three octave bands, but provides a substantial noise reduction above 300 cps, the average noise reduction above 300 cps being about 10 db. The Type B noise suppressor provides attenuation in all but the first octave band in this case, the attenuation being about 2 db in the second octave band and increasing to about 18 or 19 db in the 2400-4800 cps octave band.

From a close study of Figures 7 through 12, the following generalizations can be made. In the close field, the Type A noise suppressor, in general, 1) increases the SPL's at the close field measuring positions in the frequency range from 20-600 cps, 2) affords some noise reduction, about 5-10 db, from 600-4800 cps, 3) provides little change in the SPL in the 4800-10,000 cps band. Thus, the major effect of the noise suppressor in the region close to the aircraft is to redistribute the acoustic power, but to cause little or no change in overall SPL.

In the close field, the Type B noise suppressor provides noise reduction at all frequencies above 75 cps. Below 75 cps the noise reduction is negligible. The noise reduction which is a few db in the 75-150 cps octave band increases with increasing frequency to about 15-20 db in the 2400-4800 cps octave band. In the 4800-10,000 cps octave band the attenuation is about 15 db. The secondary air inlet directs most of the acoustic energy in a direction normal to the longitudinal axis of the fuselage and decreases the overall sound pressure level about 10-15 db.

B. Noise Reduction at 250 Feet

All distant field SPL measurements were made on a 250-foot circle centered at the exhaust orifice of the aircraft. As can be seen on the plot plan of the measurement site in Figure 4, measurements could not be made around 360° of the circle due to the presence of various obstructions such as blast fences and signboards. In addition, during measurements on the unsuppressed aircraft, the noise suppressor itself shielded the right (starboard) semicircle.

Measurements of the SPL around the unsuppressed aircraft were made twice; once during the survey of the Type A noise suppressor and once during the survey of the Type B noise suppressor. Due to the presence of the signboard on the northeast side of the runway and the blast fence on the east side of the runway, it was not possible to obtain measurements at angles less than 10° from the nose of the aircraft. In addition, the presence of the signboard at 90° from the nose made interpolation necessary to obtain reliable data at this point. The data presented represent the average value of the two sets of measurements. In general, the spread in data was less than 3 db. At higher frequencies a greater spread was noted at some angles.

Measurements were made around the Type A noise suppressor from 45° on the right (starboard) side to 10° on the left (port) side, covering a total of about 305° of the circle. Data at the same angle from the jet stream on either side have been averaged.

When the measurements were made on the Type B noise suppressor, many aircraft were parked on the left side of the noise suppressor and it was thus impossible to make measurements on the port side. Therefore, measurements were made from 180° to about 40° from the nose on the starboard side and repeated, traversing from 40° back to 180°.

The distant field data are presented in Figures 13 through 20 in the form of SPL versus angle from the nose in each of the eight octave bands. The acoustical analysis of the noise suppressor in the far field is obtained entirely from these data.

One notices from the figures that the Type B noise suppressor is more effective than the Type A noise suppressor. That is, at all angles and in all frequency bands, a lower SPL was measured at 250 feet when the Type B noise suppressor was attached.

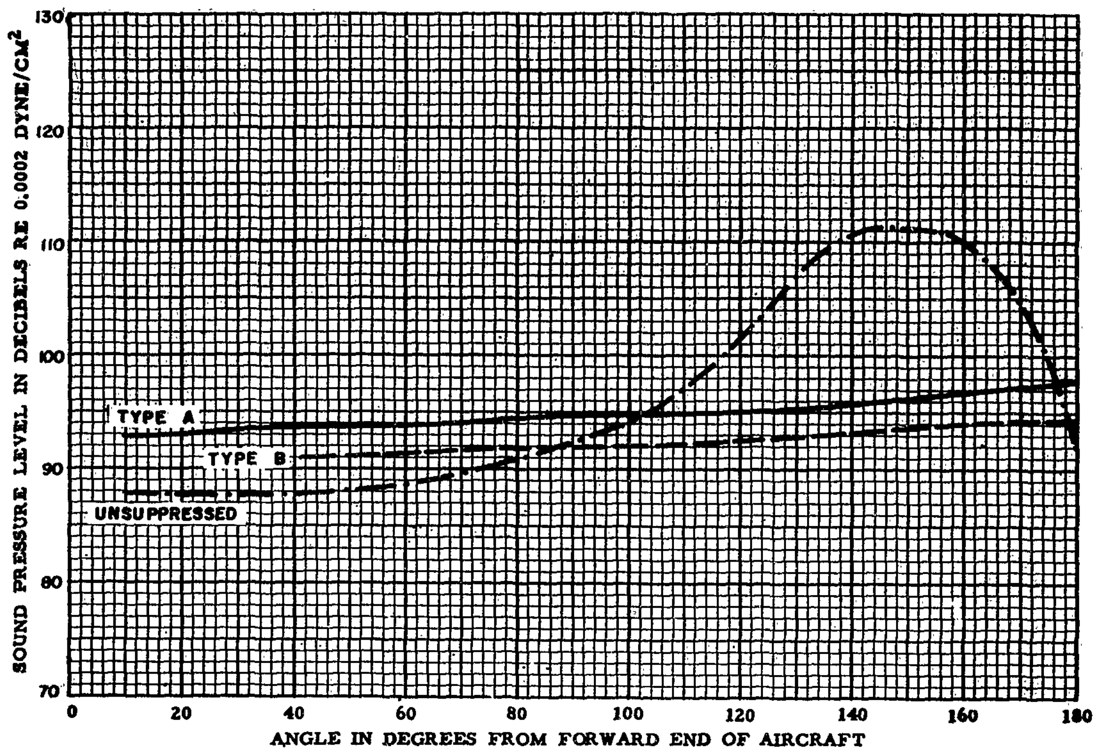


Figure 13. SPL at 250 Feet; 20-75 CPS

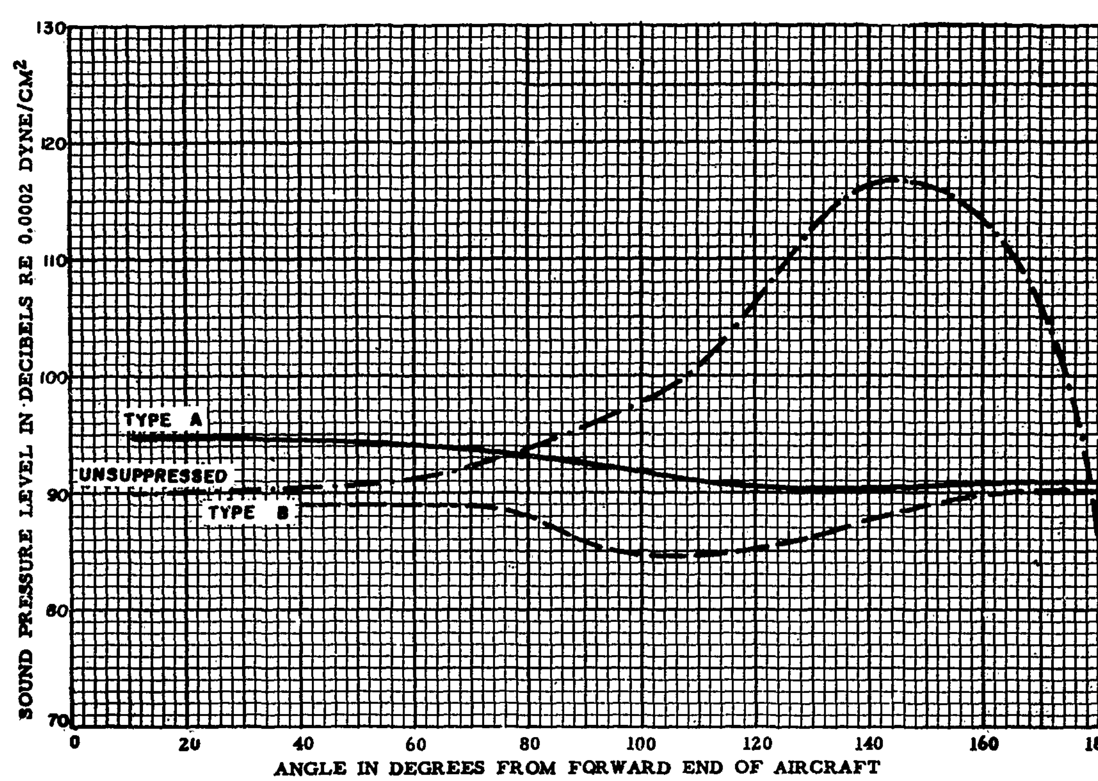


Figure 14. SPL at 250 Feet; 75-150 CPS

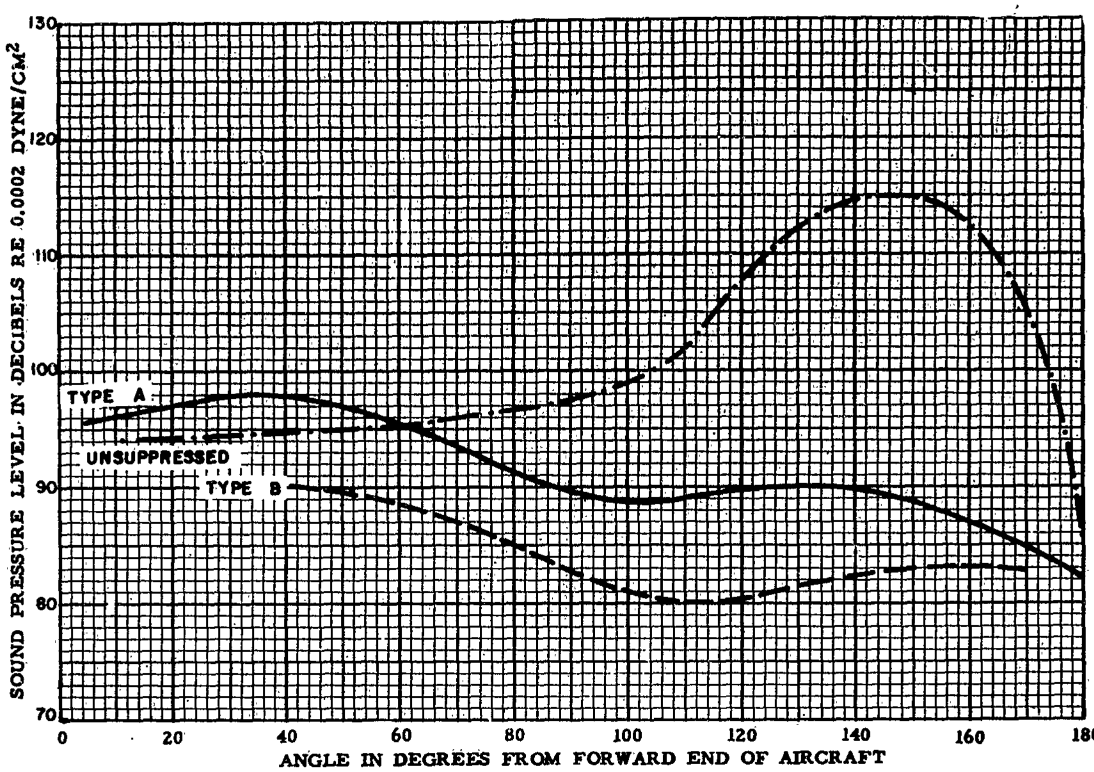


Figure 15. SPL at 250 Feet; 150-300 CPS

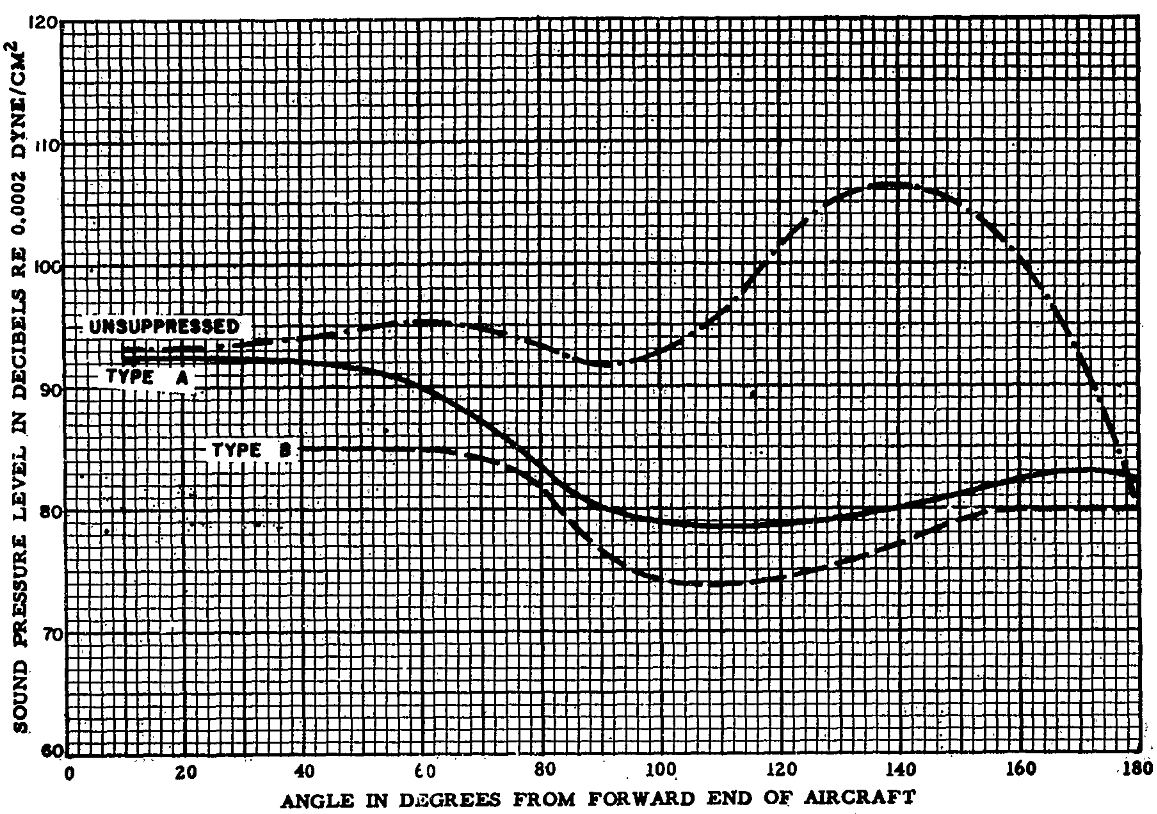


Figure 16. SPL at 250 Feet; 300-600 CPS

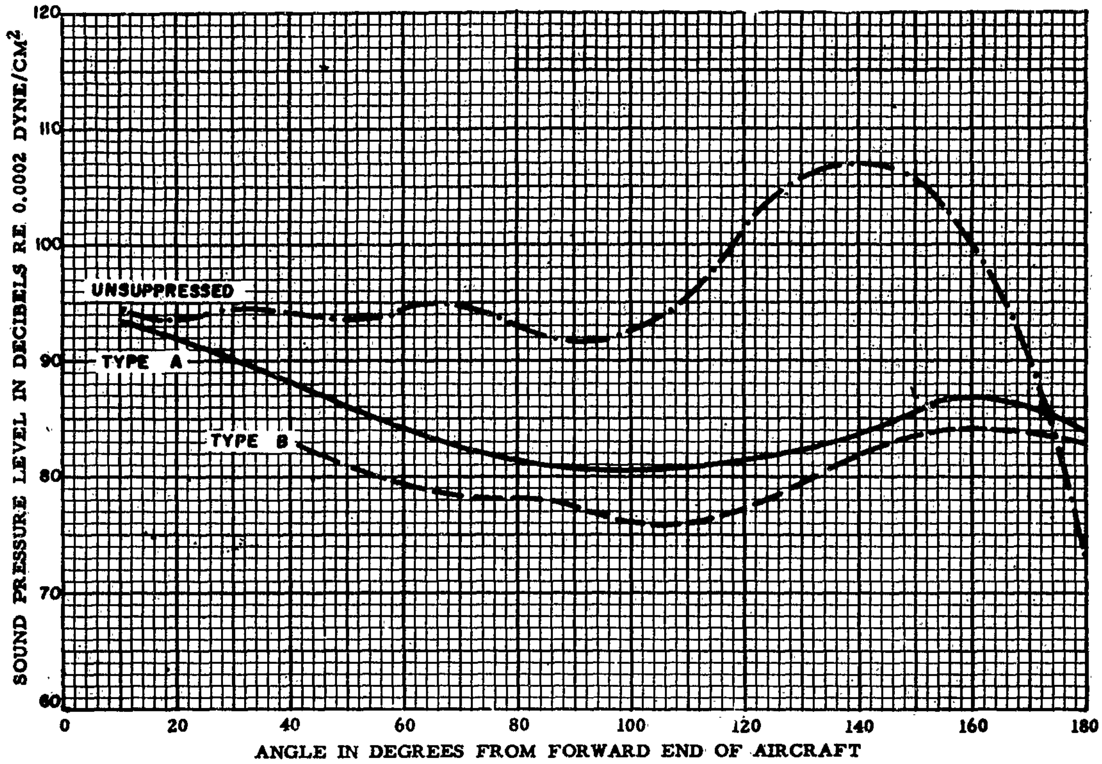


Figure 17. SPL at 250 Feet; 600-1200 CPS

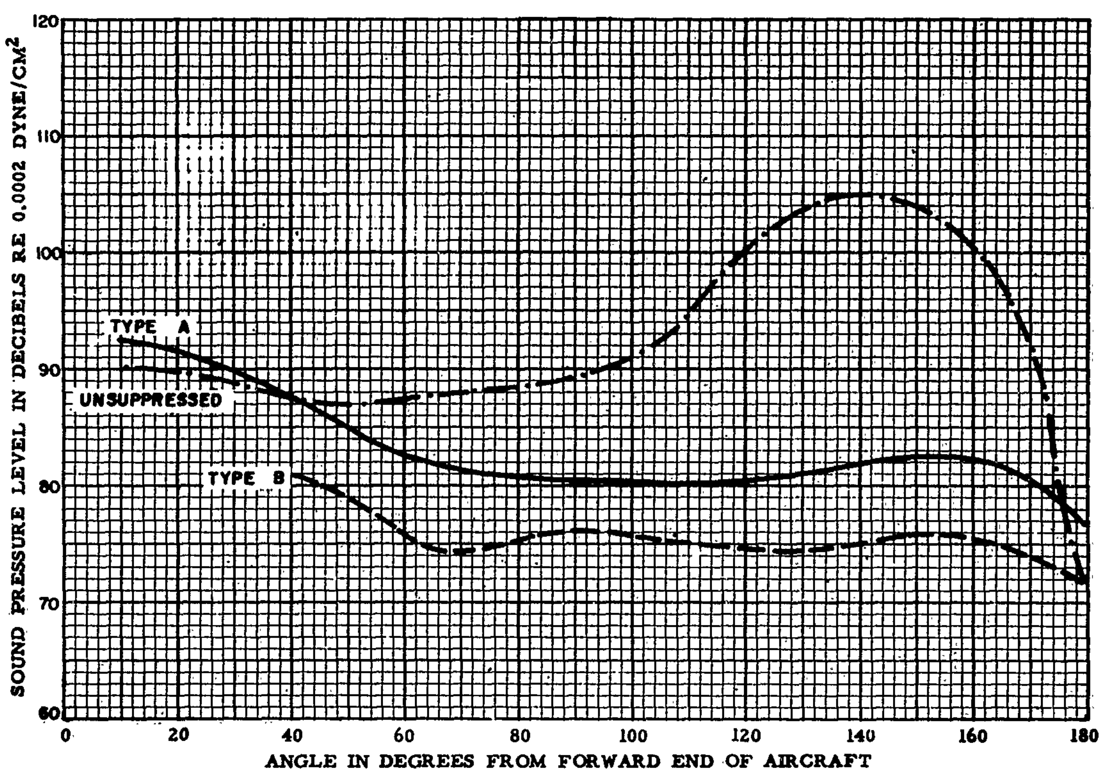


Figure 18. SPL at 250 Feet; 1200-2400 CPS

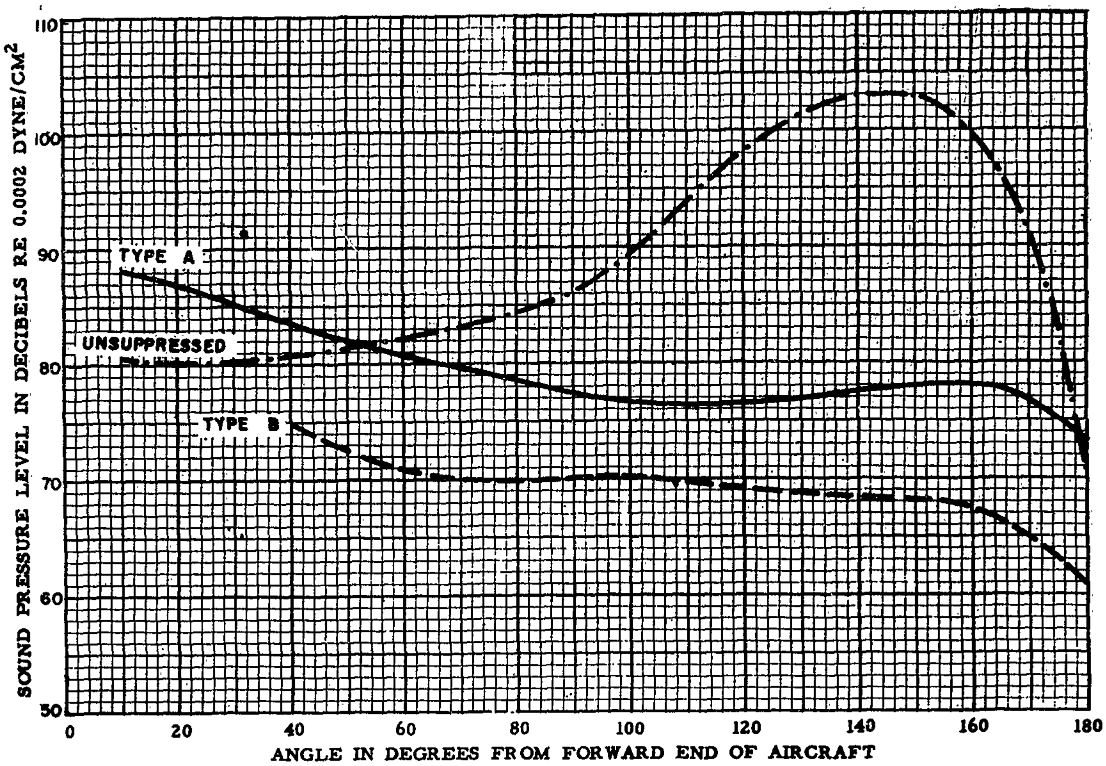


Figure 19. SPL at 250 Feet; 2400-4800 CPS

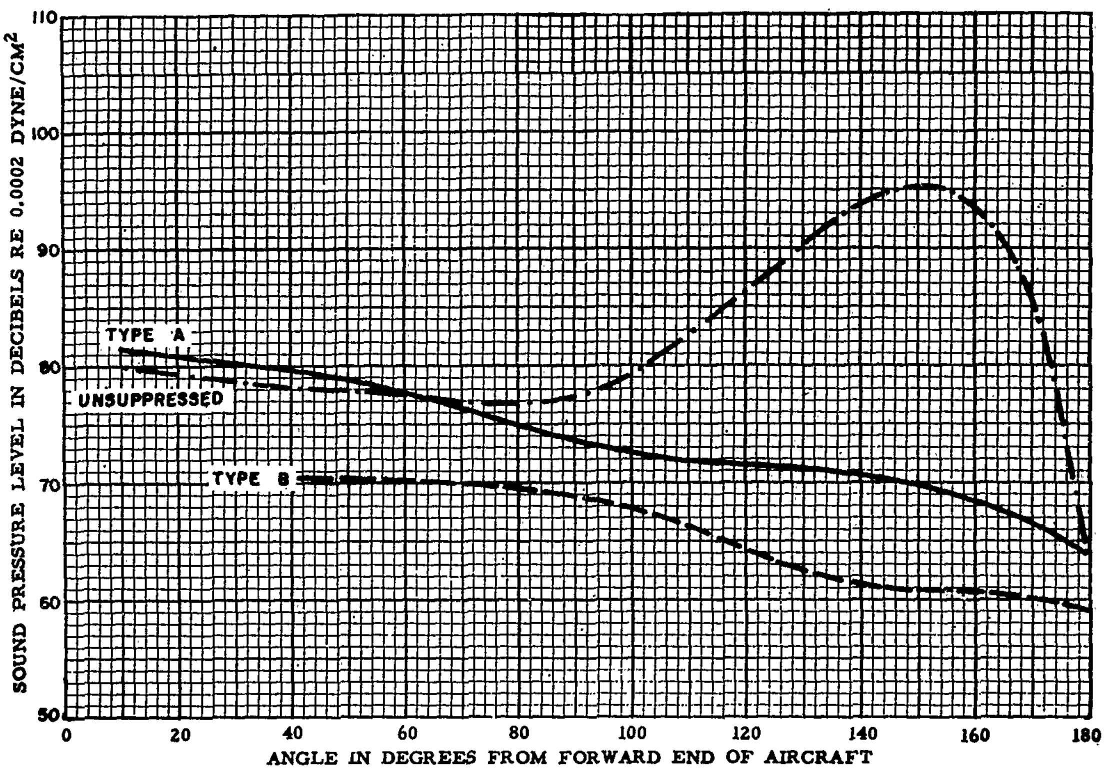


Figure 20. SPL at 250 Feet; 4800-10,000 CPS

Either noise suppressor (Type A or Type B) produces a less directive noise field than the unsuppressed jet engine. The noise reduction is therefore largest in the region from 160° - 110° from the nose of the aircraft where the directivity index of the unsuppressed aircraft is largest.

In Figure 21, the noise reduction at 250 feet is plotted as a function of angle for the 600-1200 cps octave band. This plot shows that behind the aircraft there is a gain in SPL over the angular range from 180° - 170° for both noise suppressors. The noise reduction in this octave band is a maximum of about 23 db for the Type A noise suppressor, and about 26 db for the Type B noise suppressor in the region from 140° to 130° from the jet stream. The noise reduction decreases with decreasing angle from 130° and, in the case of the Type A noise suppressor, approaches 0 db towards the front of the aircraft. The noise reduction of the Type B noise suppressor system decreases with increasing angle, but remains about 5 db greater than that of the Type A system.

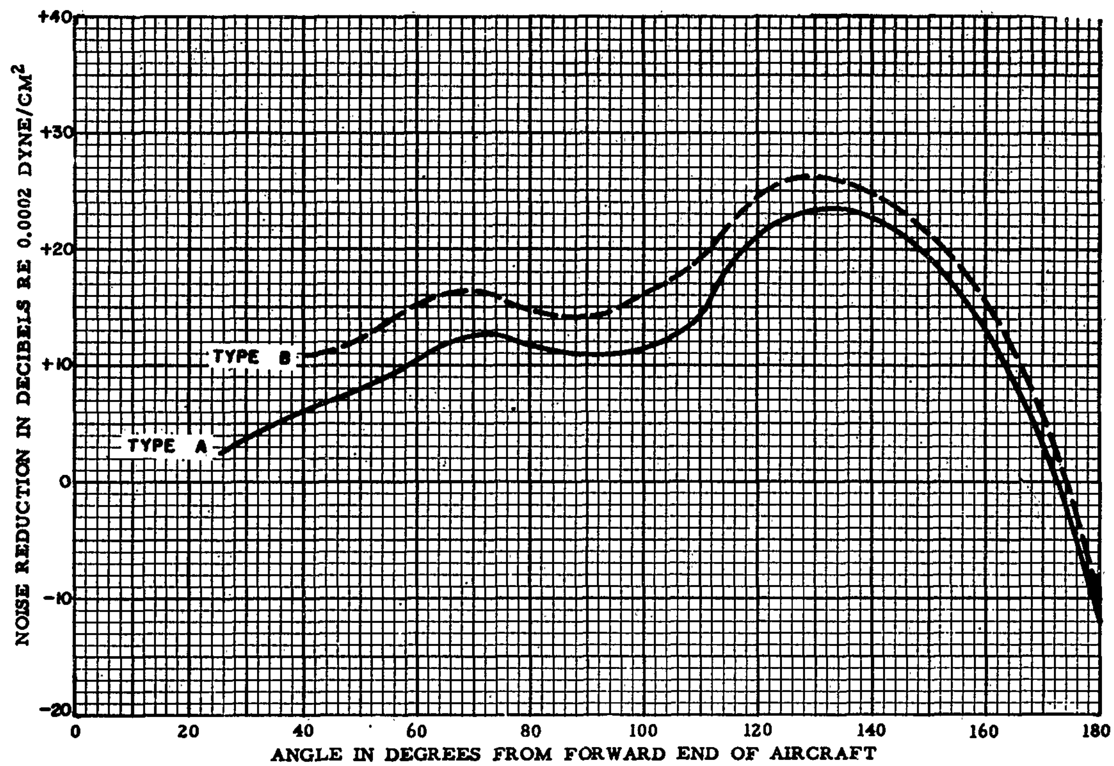


Figure 21. Noise Reduction at 250 Feet; 600-1200 CPS

In Figure 22, the noise reduction at 250 feet is plotted as a function of angle for the 75-150 cps octave band. The maximum noise reduction in this band is about 26 db for the Type A noise suppressor, and 29 db for the Type B noise suppressor. The noise reduction of the Type A noise suppressor becomes negative in this band at about 80° from the nose and remains negative at all lower angles. The noise reduction of the Type B noise suppressor decreases from the maximum with decreasing angle but remains positive in the forward quadrant.

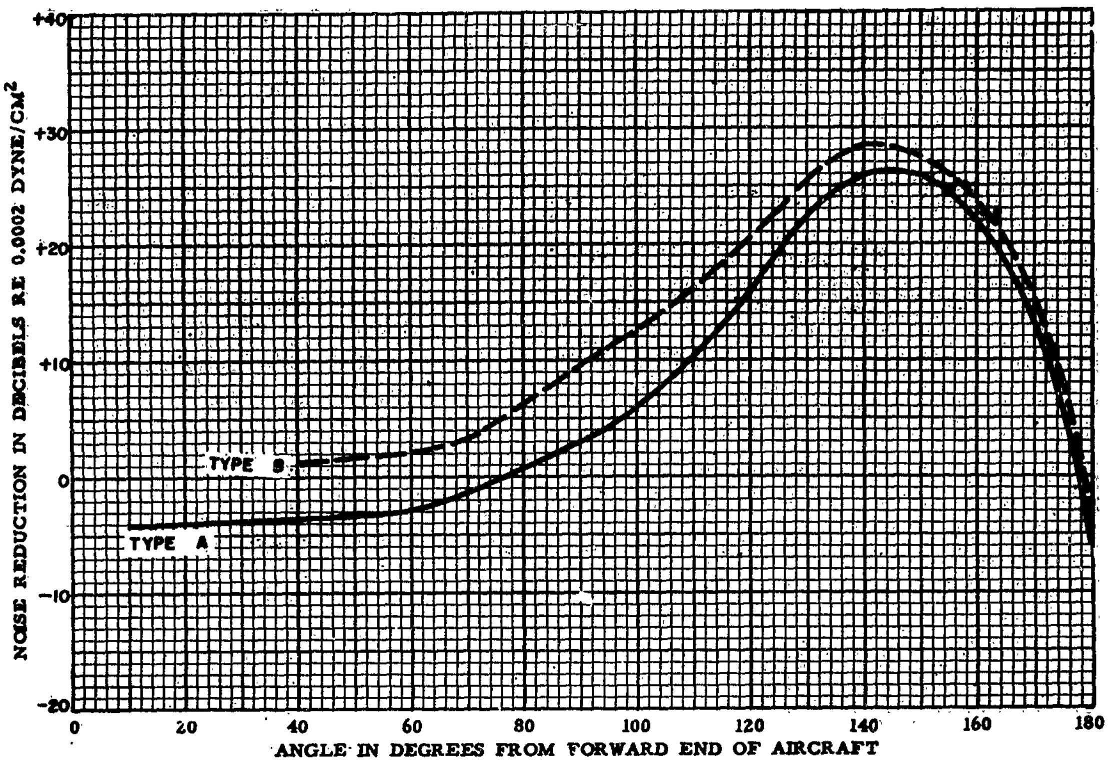


Figure 22. Noise Reduction at 250 Feet; 75-150 CPS

Some of the data presented in Figures 13 through 20 are presented in a different manner in Figures 23, 24, and 25. In these figures the noise reduction at a given position is plotted as a function of octave bands of frequency.

In Figure 23 the noise reduction at 250 feet measured at 140° from the jet stream is plotted as a function of octave bands of frequency. These curves represent the maximum noise reduction obtained in the distant field. The average noise reduction obtained above 75 cps is about 25 db for the Type A noise suppressor and somewhat greater than 30 db for the Type B system. It can be seen here that the noise reduction obtained with the Type B noise suppressor is from 2 to about 10 db greater than the noise reduction measured for the Type A noise suppressor. The noise reduction at 140° is positive in all octave bands of frequency.

In Figure 24 the noise reduction at 250 feet measured at 90° is presented as a function of octave bands of frequency. At 90° the Type A system provides a positive noise reduction in all octave bands except the first, where the noise reduction is about -2 db. The Type B noise suppressor provides a noise reduction about 2 to 8 db greater than the Type A noise suppressor, and is positive at all frequencies.

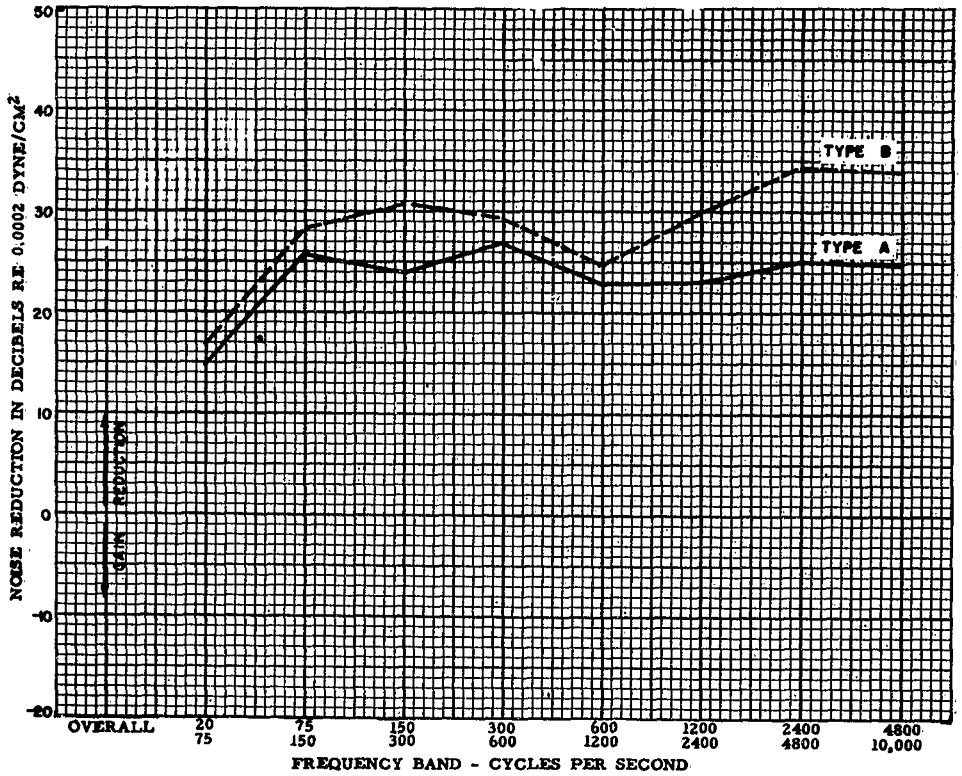


Figure 23. Noise Reduction at 250 Feet Measured 140° from the Nose of the Aircraft

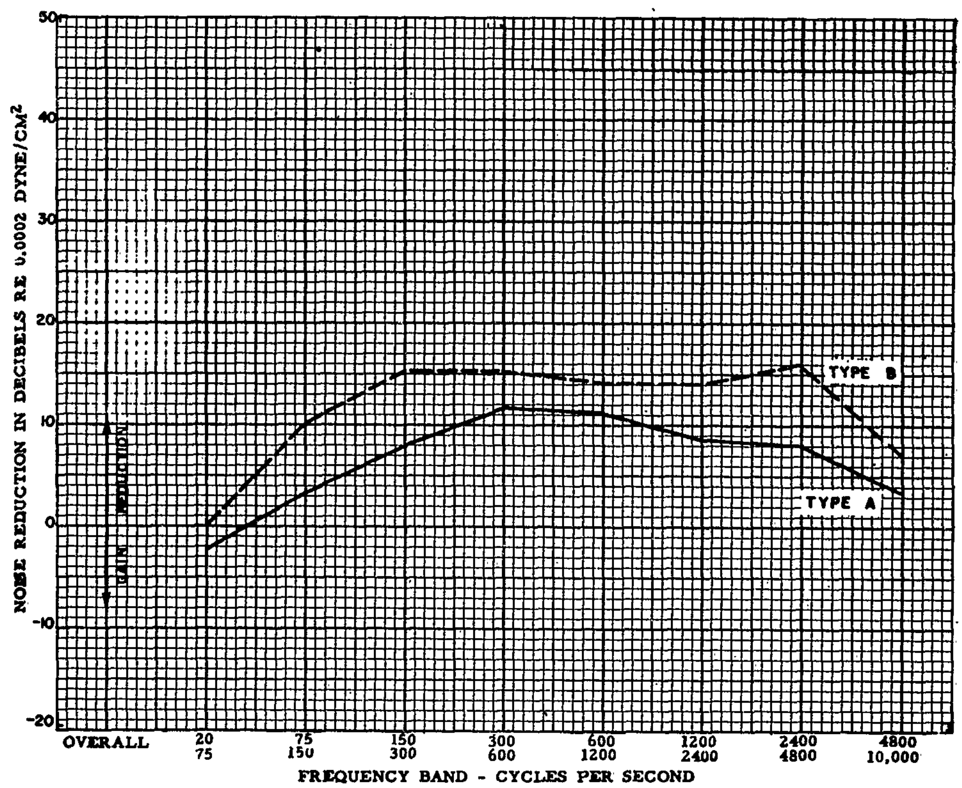


Figure 24. Noise Reduction at 250 Feet Measured 90° from the Nose of the Aircraft

Finally, in Figure 25 the noise reduction at 250 feet measured at 50° is presented as a function of octave bands of frequency. In this case the noise reduction obtained by the Type A noise suppressor is negative in five octave bands of frequency and positive in only three. The Type B noise suppressor is again 2 to 10 db better than the Type A noise suppressor, and provides a negative attenuation in only one octave band of frequency (20-75 cps).

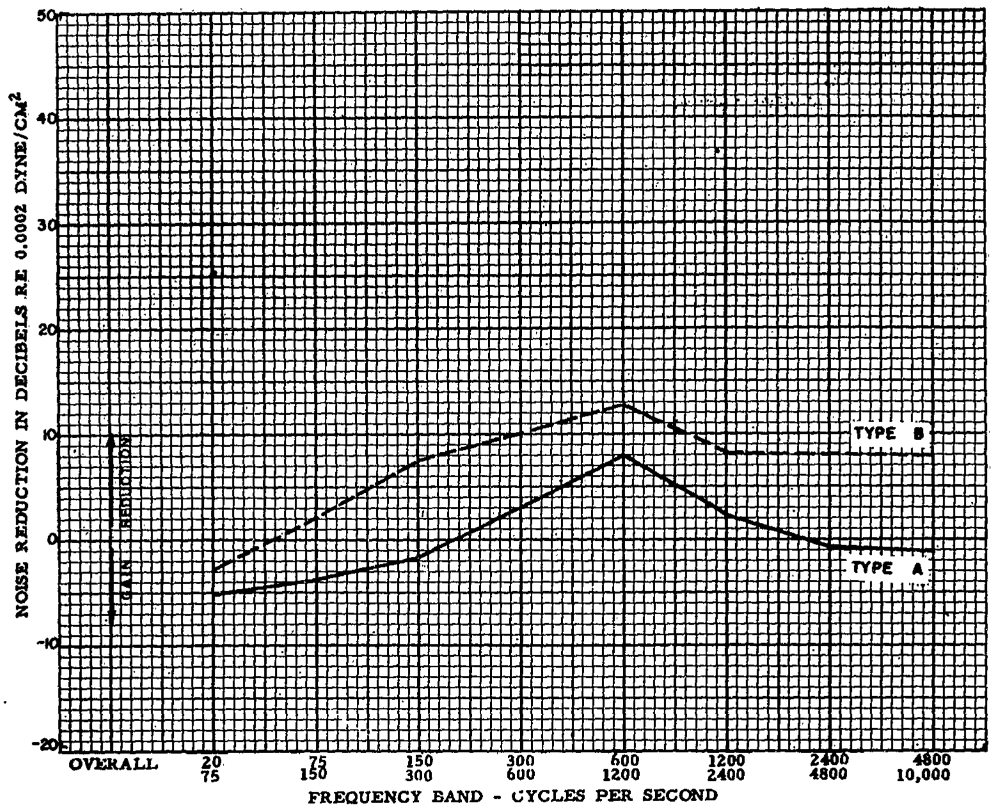


Figure 25. Noise Reduction at 250 Feet Measured 50° from the Nose of the Aircraft

In summary, then, comparison of the Type A and Type B noise suppressors in the distant field shows that the noise reduction obtained with the Type B noise suppressor is about 2 to 10 db larger than that obtained with the Type A noise suppressor. The greater increase in noise reduction is obtained at higher frequencies and the lesser increase is obtained at the lower frequencies. The noise reduction of the Type B noise suppressor is generally positive, whereas the noise reduction of the Type A noise suppressor is negative in some octave bands at several positions.

C. Average Reduction of Sound Pressure Level on 250-Foot Semicircle

Another method of describing the acoustical effectiveness in the distant field of a ground run-up noise suppressor is to specify the reduction in average SPL afforded by the noise suppressor. By averaging the SPL over a semicircle, azimuth is eliminated as an independent variable and thus a single plot of noise reduction as a function of frequency will suffice to describe the noise suppressor. The distance at which the average noise reduction is determined should be retained as an independent variable but the reduction in average SPL will not vary very much as a function of distance provided the measurements of SPL are made in the far radiation field of the suppressor. The averaging yields a single set of numbers to specify the noise reduction of the noise suppressor. Simplicity is obtained at the expense of directivity information and hence the results are useful only for rough comparison of mufflers and cannot be used for design purposes.

To determine the average sound pressure level, the semicircle is divided into "n" sub-angles of $\frac{180}{n}$ degrees. The average SPL's in each subdivision are added in a logarithmic sense to one another and 10 $\log_{10} n$ is subtracted from the total to obtain the average SPL. This operation is carried out both for the SPL measured on the circle with the unsuppressed jet engine and with the suppressed jet engine. The difference between these two average SPL's is then the average noise reduction afforded by the noise suppressor.

In Figure 26 the average SPL obtained by the method above is given for the unsuppressed aircraft and for the Type A and Type B noise suppressors.

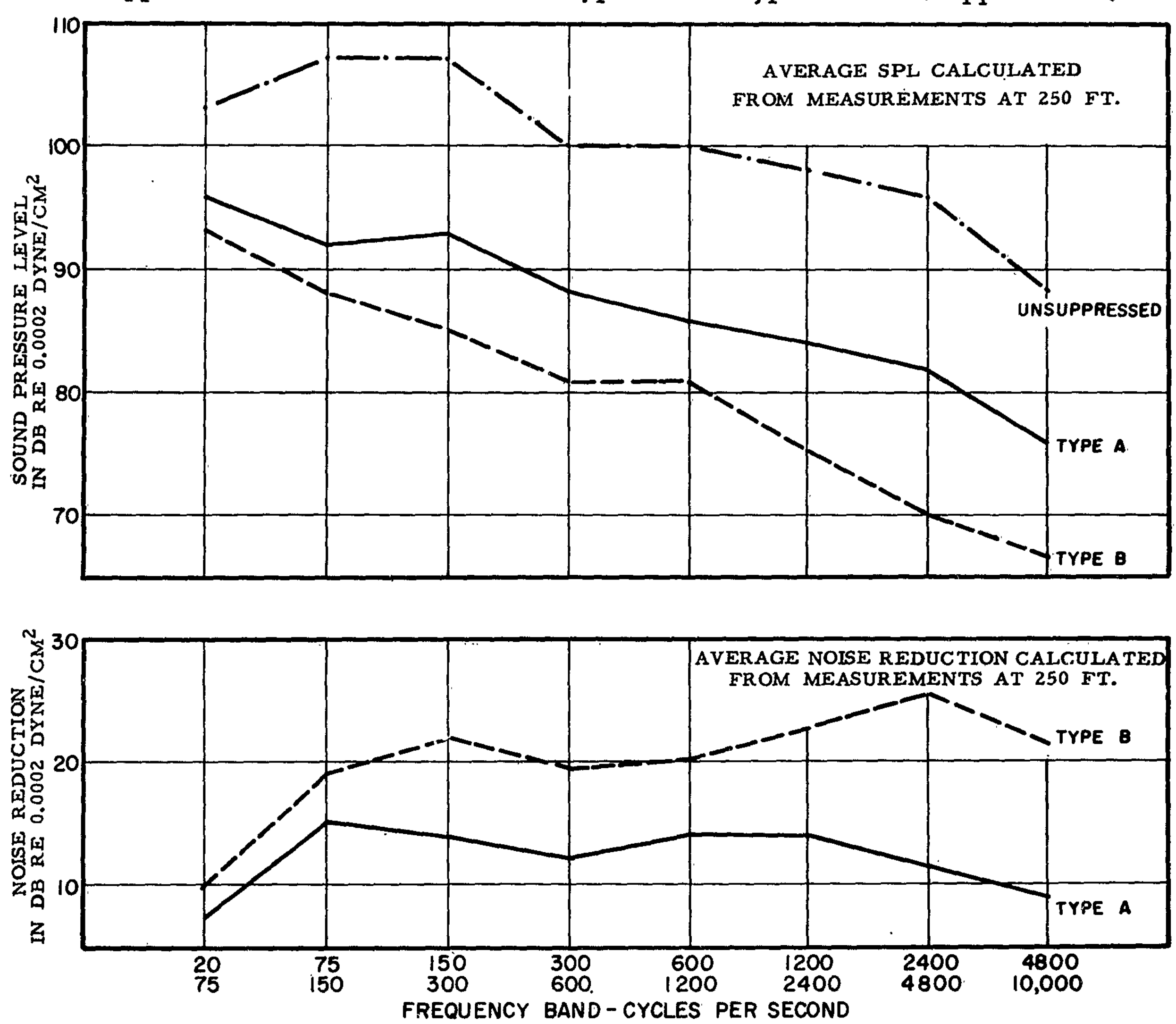


Figure 26. Average SPL Calculated from Measurements at 250 Feet

Below the average SPL's, the average noise reduction for the Type A and Type B noise suppressors has been plotted. The average noise reduction for the Type B noise suppressor, in general, exceeds that of the Type A noise suppressor by about 8 db. The difference in noise reduction is lower at low frequencies and higher at high frequencies. It is of interest to note that the differences in noise reduction are of the same order of magnitude as were determined at the close-in positions (Figures 11 and 12).

Both of the noise reduction curves are relatively flat above the first octave band. The average value of the average noise reduction from 75 to 10,000 cps is about 14 db for the Type A noise suppressor and about 21 db for the Type B noise suppressor.

SECTION IV

EVALUATION OF THE RELATIVE MAGNITUDE OF THE MAJOR NOISE SOURCES

To determine the relative magnitude of three major noise sources present in the aircraft noise suppressor combination, measurements of SPL were made over the primary air intake opening at the nose, over the secondary air intake at the coupling, and over the exhaust plane of the noise suppressor. These measurements were made by moving the microphone slowly over each of the openings. A 1-second time constant was used during data reduction to obtain the average value of SPL over each opening.

The results of the measurements are shown in Figure 27. In order to determine the contribution to the average SPL in the distant field of each of these sources, the power level (PWL)* of each of the sources must first be determined. The SPL at 250 feet is then found by use of the following relation:

$$\mathrm{SPL} = \mathrm{PWL} - 10 \log_{10} 2\pi(250)^2$$

This equation implies that the total sound energy radiated by each of these sources passes uniformly through a hemisphere of radius 250 feet surrounding the source and gives the average value of the SPL over that hemisphere. Since the exhaust stack radiates more acoustic energy in a direction normal to the plane of the stack opening than in a horizontal direction, a directivity correction must be applied. (The directivity corrections are taken from Reference 1). The following areas have been used in calculating the average SPL's at 250 feet: area of exhaust - 30 square feet; area of the opening at the Type A coupling - 12 square feet; area of the opening at the Type B coupling - 17 square feet; area of the primary air inlet opening - 3 square feet.

The resulting estimated SPL's at 250 feet calculated by the above method for each of the sources are plotted in Figure 28. The total SPL in the case of the

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*$\mathrm{PWL} = 10 \log_{10} \dfrac{W}{10^{-13}}$, where W is the acoustic power in watts.

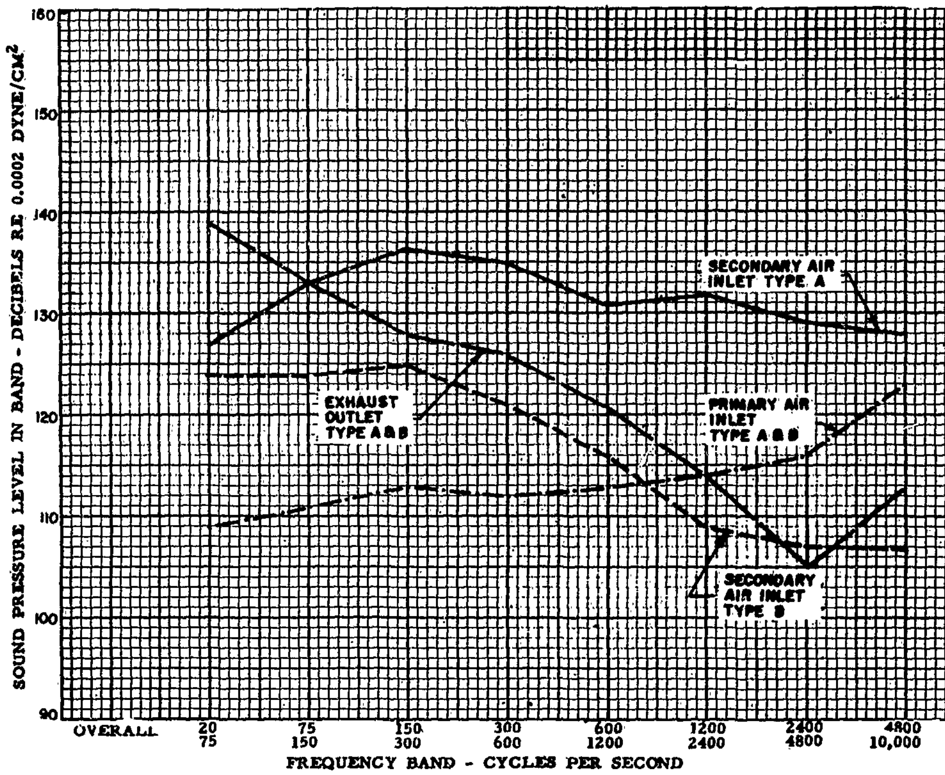


Figure 27. SPL at Near Field Noise Sources; F84F; 100% RPM

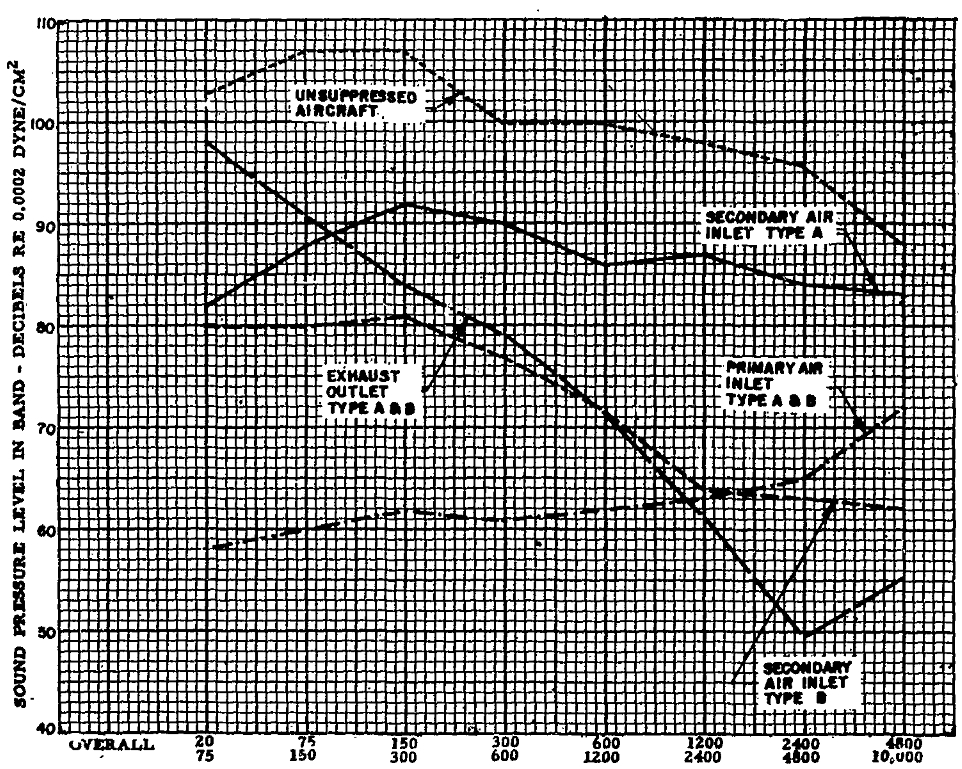


Figure 28. Contribution to Total Average SPL at 250 Feet from Each Near Field Noise Source

Type A noise suppressor is obtained by appropriately adding curves 1, 2 and 4 of Figure 28. In the case of the Type B noise suppressor, the total SPL can be obtained by adding curves 1, 3 and 4. With the Type A noise suppressor attached, the average SPL measured at 250 feet as estimated by this analysis will be mainly determined by the exhaust stack in the 20-150 cps region, and in the 150-10,000 cps region by the secondary air intake opening. With the Type B noise suppressor, however, the contribution from the coupling is much lower, and the exhaust stack radiation is important at 250 feet in the frequency range from 20-2400 cps. Above 1200 cps, the intake noise also becomes important. It is interesting to note that in the 1200-2400 cps octave band, the contributions from each of the three sources are about equal.

This analysis also shows that although an increase in noise reduction of the secondary air inlet of about 14 db in 150-300 cps band, for example, has been obtained by addition of the new coupling, the increase in noise reduction at 250 feet will be significantly less than 14 db (as measured, the increase in noise reduction is about 8 db) since the exhaust noise is the major contributor to the SPL at 250 feet. This result is also true in some of the other octave bands. Thus it would appear that a further increase in the acoustical effectiveness of the secondary air inlet is not warranted. As the Type B noise suppressor now stands, it is a well-balanced acoustical design. A further significant increase in noise reduction could only be obtained by simultaneously improving the coupling, acoustic treatment in the coupling and the exhaust unit, and by applying noise suppression to the primary air inlet.

Finally, Figures 29 and 30 are presented to show a comparison of the calculated average SPL obtained from measurements in the near field and the average SPL obtained from distant-field data. The comparison is quite good for the Type A noise suppressor, the two curves lying within about 2 db of one another in almost all frequency bands.

In the case of the Type B noise suppressor, the discrepancies are larger. In the low-frequency bands the discrepancies may arise from possible wind noise at the measuring microphone over the exhaust plane. The data in the 600-1200 and 1200-2400 cps bands in Figure 29 indicate that the measured SPL's are about 6 db higher than was estimated from the near field measurements. A possible cause of this discrepancy is that all of the major sources have not been accounted for. For example, noise transmitted through the walls of the eductor tube or the suppressor unit may contribute significantly to the SPL's at 250 feet.

In addition, the differences may be explained by a consideration of the directional characteristics of the various noise sources. For instance, the calculated SPL at 250 feet due to the coupling and air inlet corresponds to the average SPL over an entire hemisphere. In this analysis, the average SPL over the entire hemisphere is compared with the average SPL on one particular great

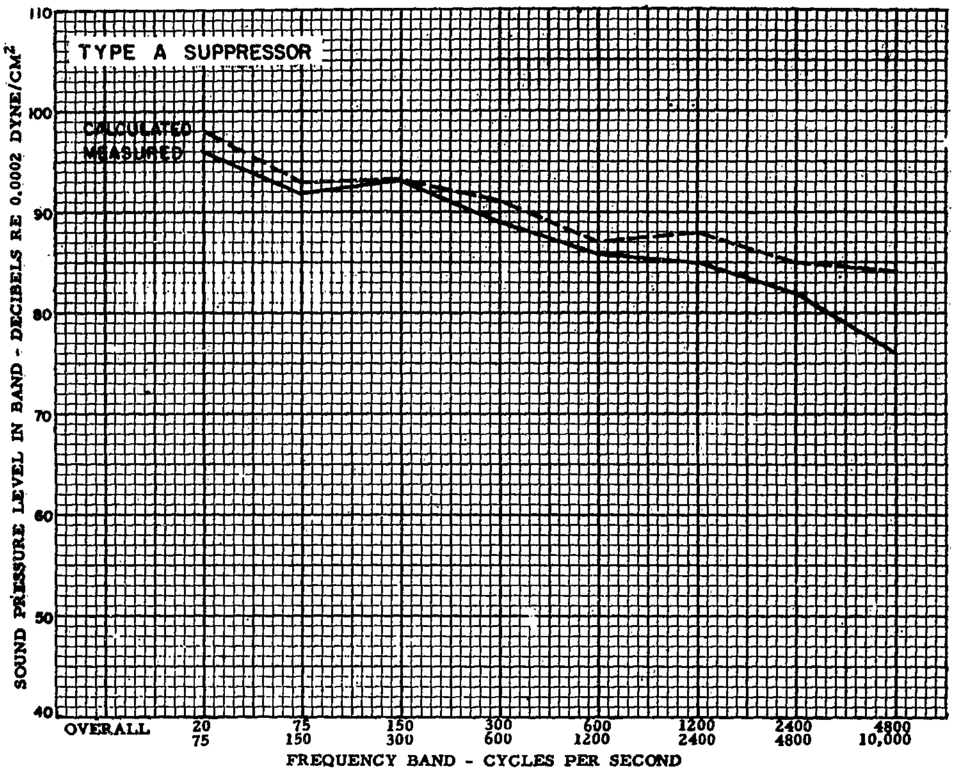


Figure 29. Comparison of Measured and Calculated Average SPL at 250 Feet, Type A Noise Suppressor

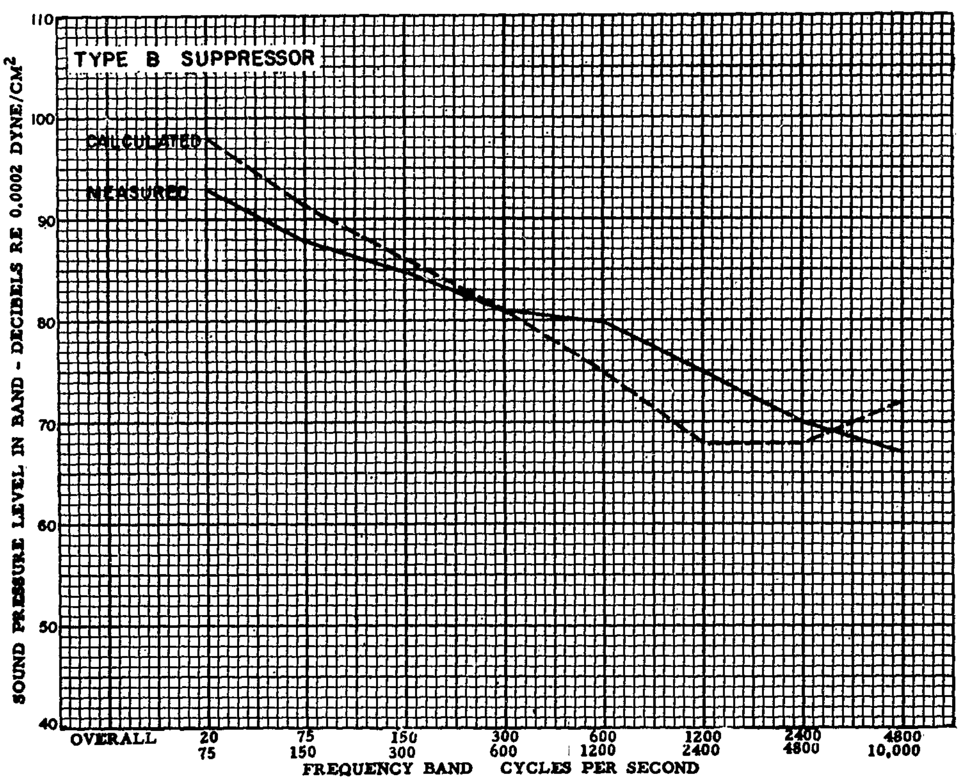


Figure 30. Comparison of Measured and Calculated Average SPL at 250 Feet, Type B Noise Suppressor

circle of the hemisphere, namely, a great circle near the ground plane. As an engineering approximation, these two average SPL's are equal for the Type A coupling and the air inlet opening. They are probably not equal in the case of the Type B coupling due to the geometry of the system (Figure 3). In this instance most of the acoustic energy is radiated in a horizontal direction and very little in a vertical direction. Therefore, the average SPL near the ground (in the measured plane) is probably higher than the average value of the SPL over the hemisphere. Consequently, the calculated SPL's at 250 feet would be lower than the measured SPL's in the frequency range where the secondary air inlet makes a significant contribution.

REFERENCE

1. Staff of Bolt Beranek and Newman Inc., Handbook of Acoustic Noise Control, Volume I, Physical Acoustics, WADC Technical Report 52-204, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, April 1953.

APPENDIX A

SOME NON-ACOUSTICAL ASPECTS OF THE DURASTACK NOISE SUPPRESSOR

The noise reduction characteristics are the most important characteristics of a ground run-up noise suppressor, since noise reduction is the sole reason of existence of the suppressor. However, certain other factors determine the practical usefulness of the noise suppressor. Among these factors are:

1) Ease of maintenance.

2) Adaptability to other aircraft and/or engines.

3) The effort and time involved in joining an aircraft to the noise suppressor.

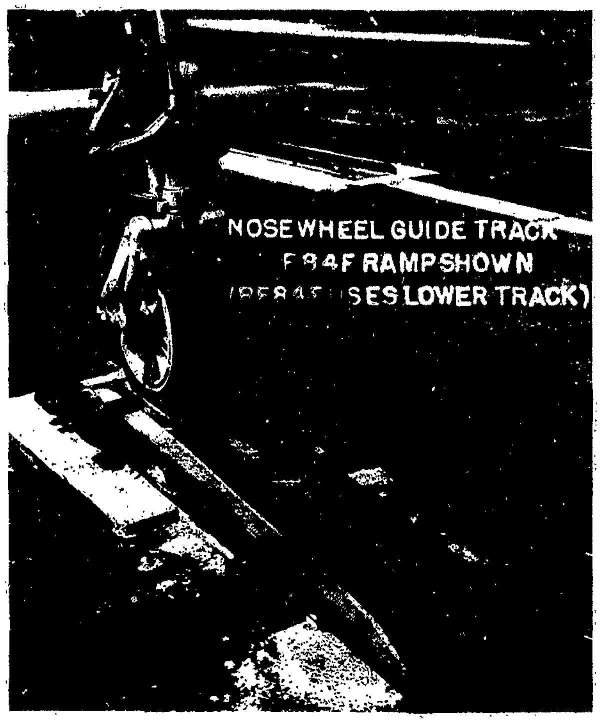
Part One of this appendix details the mechanics of the operations of removing and inserting an aircraft into this suppressor. The figures included in this section, as well as the operating instructions for use of the suppressor were obtained directly from Republic Aviation Corporation. A few introductory paragraphs have been added to the operating instructions to assist the reader who has not seen the noise suppressor in operation.

Part Two of this appendix is a summary report by R.C. Bergh of Republic Aviation Corporation on the design requirements of the noise suppressor and some comments on the performance of the system.

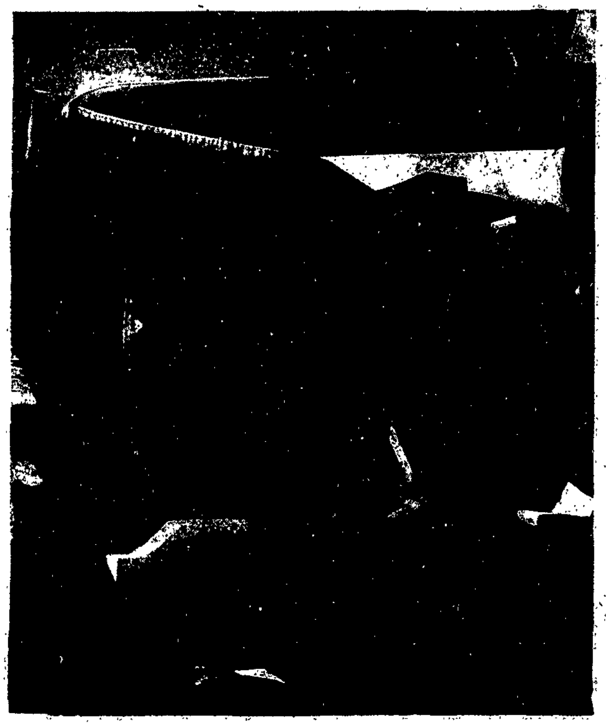
PART ONE - Insertion and Removal of Aircraft

Two major problems associated with the design of a coupling between a noise suppressor and an aircraft are 1) positioning of the aircraft relative to the suppressor, and 2) motion of the aircraft during engine operation. The problem of motion of the aircraft has been approached in two ways in the design of this noise suppressor. First, the aircraft is stabilized relative to the noise suppressor by locking the landing wheels in a fixed position and then mechanically locking the oleo struts to prevent their motion during operation of the engine. Second, the residual motion is accounted for by allowing for movement of the aircraft relative to the coupling.

The aircraft is positioned relative to the noise suppressor by the use of steel-wheel guide tracks which may be seen in Figure A-1. Bumpers on the rear portion of the main landing gear guide tracks provide fore and aft positioning of the aircraft with respect to the suppressor. Since this noise suppressor is used both for the RF-84F and the F-84F, which have differing attitudes on the ground and resultantly different heights at the tail section, a dual nose-wheel guide track is used. This nose-wheel guide track is shown in Figure A-1.



Landing Wheel Guide Tracks
Figure A-1.



Starboard Coupling Door Open
Figure A-2.

Figure A-2 shows the right coupling door open. Notice that thick (4 inches square) sponge gasketing is used all around. The sponge gasketing at the face of the eductor tube allows the entire coupling to move longitudinally a few inches to account for slight differences in placement of the aircraft relative to the noise suppressor.

The forward portion of the coupling, which can be seen on the left-hand side of Figure A-2 can move in a vertical plane. Several large strap hinges allow this motion. The illustration No. 6 in Figure A-8 shows the spring which supports this forward portion of the coupling. When the doors are closed and tightened with a screw operated locking mechanism shown in the bottom of Figure A-2, the forward portion of the coupling fits the fuselage tightly, and moves up and down with the fuselage.

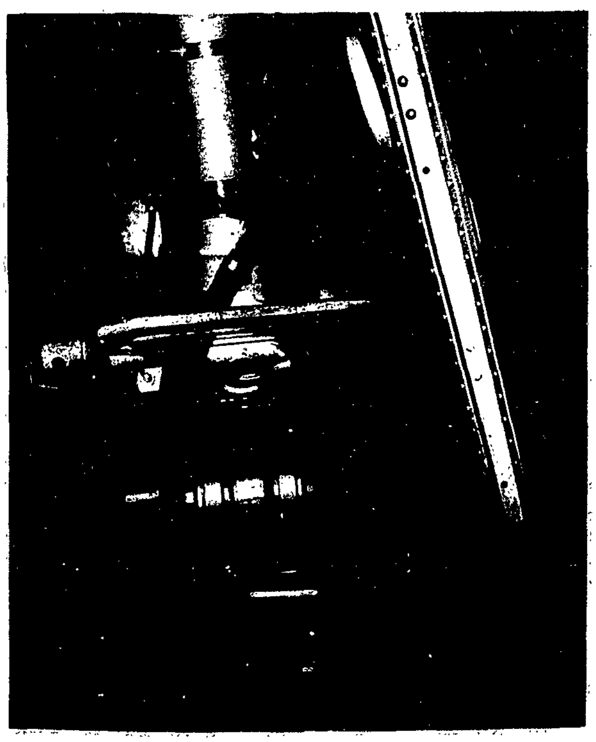
The operating instructions given below are by courtesy of Republic Aircraft Corporation. These instructions have been keyed with Figures A-1 through A-8.

Main Landing Gear Axle Lock Retracted

Figure A-3.

Main Landing Gear Axle Lock Engaged

Figure A-4.



Main Gear Oleo Deflection Lock Engaged

Figure A-5.

Nose Gear Oleo Deflection
Jack and Lock Engaged

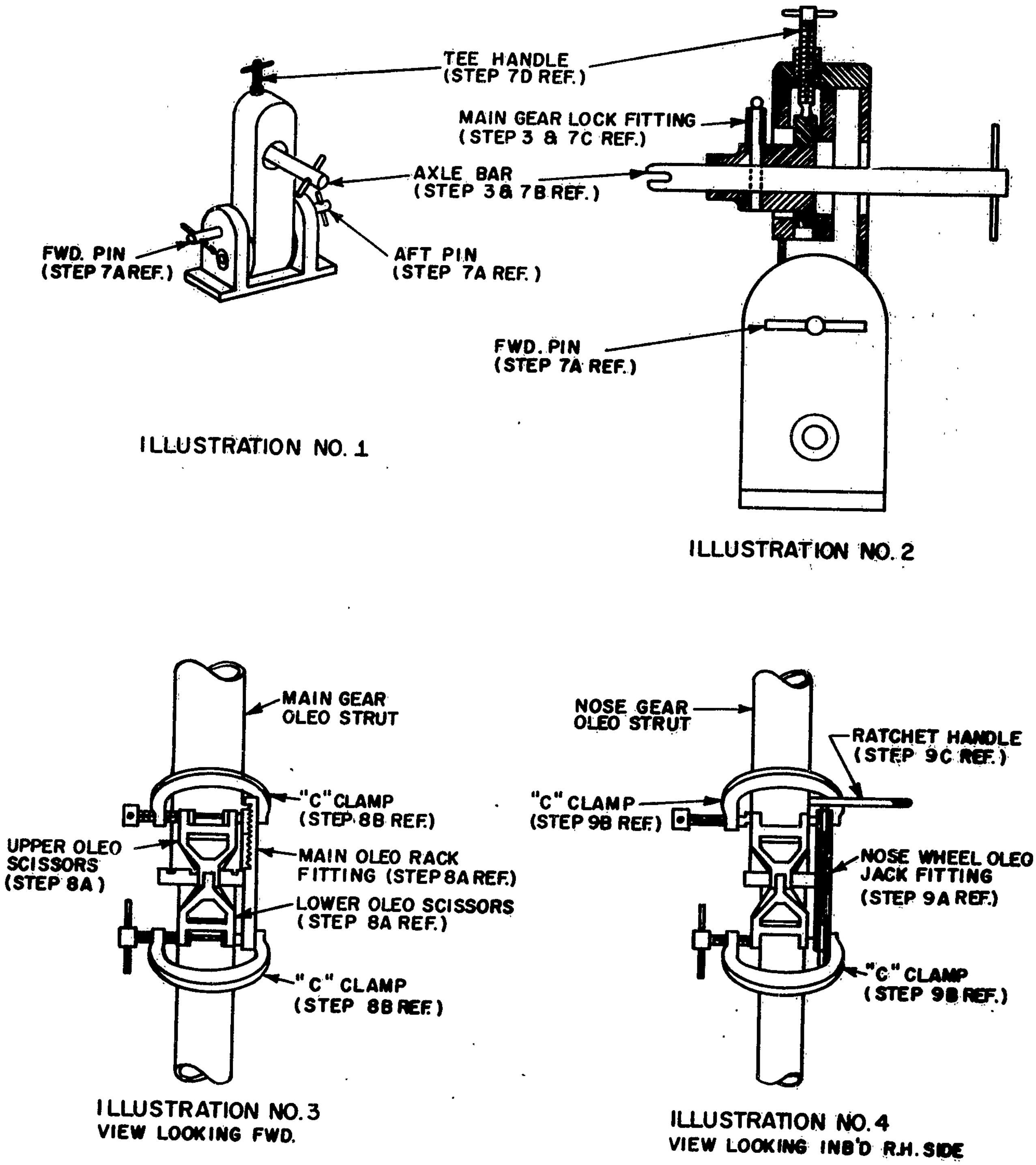
Figure A-6.

OPERATING INSTRUCTIONS

INDUSTRIAL ACOUSTICS CO. F/RF-84F MUFFLER

(Follow sequence unless otherwise noted)

To insert muffler		Figure No.	Illustration No. (See Figures A-7, A-8)
1.	Adapter doors - lock open using cables	---	---
2.	Nose wheel guide track - F84F - use ramp to raise nose wheel RF-84F - do not use ramp	A-1	---
3.	Main gear lock fittings - in retracted position - axle pins removed	A-3	1 + 2
4.	Back airplane into tracks until main wheels hit bumpers	A-3	---
5.	Remove brake bleeder access door (L + R)	A-3	---
6.	Remove screws and clip that hold anti-skid wire connector on RF airplanes only	---	---
7.	(a) Raise main gear lock fittings and insert fore and aft pins (L + R)	A-4	1 + 2
	(b) Insert axle bar through lock fitting into airplane axle	A-4	1 + 2
	(c) Insert lock pin through lock fitting and axle bar	A-4	2
	(d) Turn tee handle to apply downward force on axle (latter operation applies preload on airplane tire)	A-4	1 + 2
8.	(a) Attach main gear oleo rack fitting to upper and lower oleo scissors (L + R)	A-5	3



(Courtesy of Republic Aircraft Corp.)

Figure A-7. Details of Aircraft Tiedown System

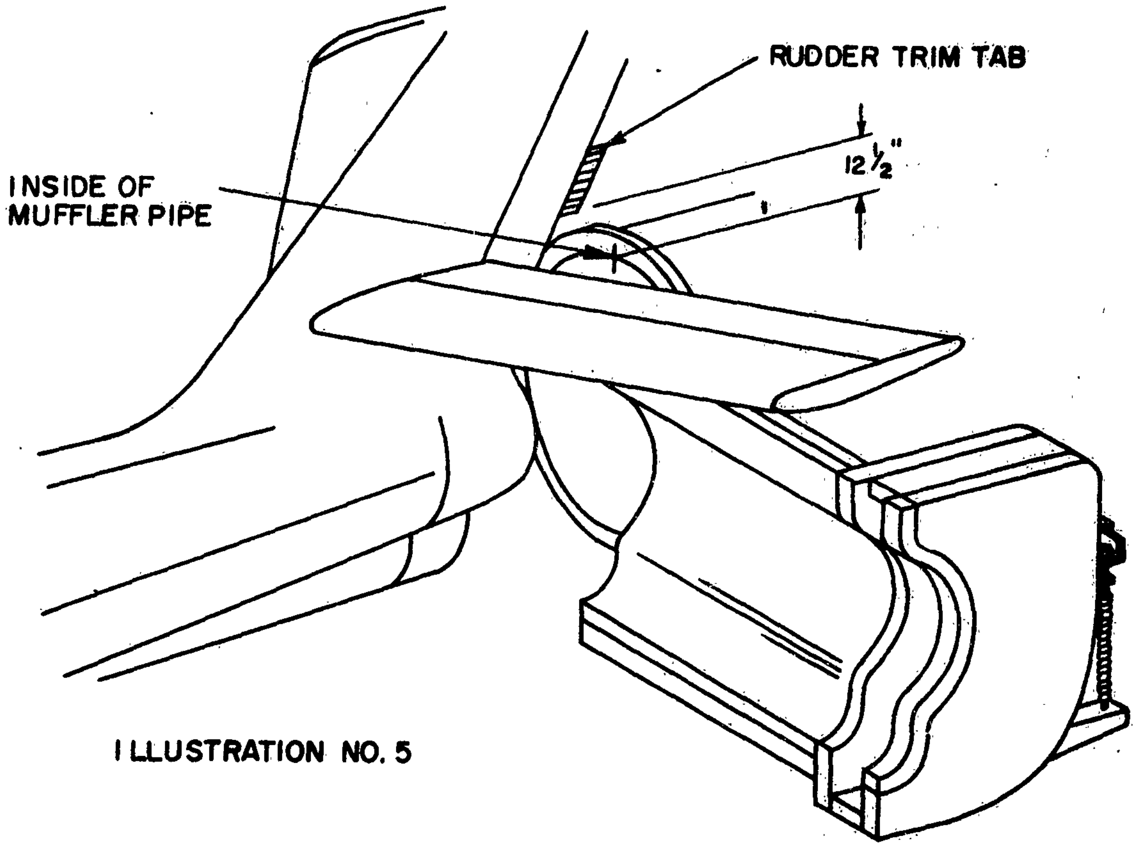


ILLUSTRATION NO. 5

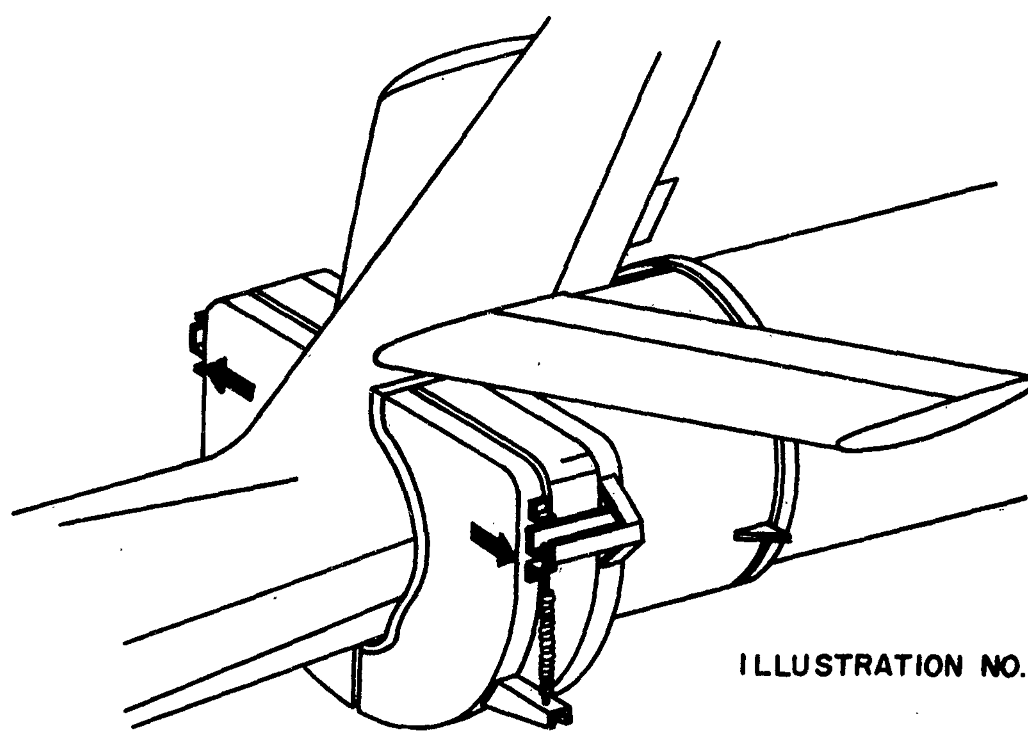


ILLUSTRATION NO. 6

(Courtesy of Republic Aircraft Corp.)
Figure A-8. Details of Coupling Section

To insert muffler (cont'd)	Figure No.	Illustration No. (See Figures A-7, A-8)
8. (b) Attach upper and lower 'C' clamps to hold rack fitting securely to scissors axles	A-5	3
*9. (a) Attach nose wheel oleo jack fitting to upper and lower oleo scissors	A-6	4
(b) Attach upper and lower 'C' clamps to hold jack fitting securely to scissors axles	A-6	4
(c) Operate ratchet handle on jack fitting screw until centerline of airplane ejector is at center of muffler pipe. Lower edge of rudder trim tab to be approximately 12-1/2 inches above inside of muffler flange	A-6	5
10. Close adaptor doors and operate hand crank until thrust stop collar on screw is engaged	A-1	5
11. Readjust ratchet on the nose gear to align lower edge of channel with arrow on adaptor door	---	6

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*These operations may be performed prior to putting airplane on tracks.

To remove from muffler: Perform operations in reverse order

Caution:

1. Stabilator must be in neutral when backing airplane into fixture.

2. Stand clear of rear of airplane and muffler during starting cycle.

3. In event of false start, wait at least 5 minutes, then open adaptor doors to permit better scavenging of muffler. Close doors before repeating starting cycle.

4. When airplane is stored in muffler or muffler is empty, lock adaptor doors open with cables. This insures complete muffler scavenging and prevents collection of explosive fumes.

5. Make sure all main gear and nose wheel oleo fittings are removed before returning plane to flight line.

6. Airplane must be securely held at main axles and all oleo deflections removed before starting engine (inspection check).

According to a letter from Mr. R. C. Bergh from Republic Aviation Corporation, "We are providing two sets of oleo clamps for each muffler station. If the clamps are attached to the aircraft prior to insertion of the muffler and removed after the airplane is pulled out, we believe the average time spent for insertion will not exceed five minutes and time for removal three minutes." This statement agrees with observations of BBN personnel during the course of the acoustical survey.

PART TWO - Summary Report on R/RF-84F Airplane Ground Muffler Installation at Republic Aviation Corporation

Prepared by R. C. Bergh
9 July 1956

Design Requirements (abbreviated)

1. The assembly shall consist of four parts, i.e., airplane coupling, augmenter, muffler and exhaust stack and shall be capable of receiving the fuller power of the Wright J65 jet engine rated at 125 pounds per second at 60°F, or 135 pounds at 0°F and 8,000 pounds thrust (maximum expected engine growth).

2. The desired average attenuation in the aft quadrant (exhaust) at a distance of 100 feet shall be 20 db minimum in each octave band between 37.5 and 9600 cycles per second. As much attenuation as possible shall be provided in the forward quadrant without unduly complicating the installation and increasing the time for attaching the airplane. No primary air intake silencer shall be provided.

3. No external power (electric, pneumatic or hydraulic) shall be required and secondary air shall be used to cool the airplane tail structure and internal parts of the muffler assembly. No part of the airplane structure shall be subjected to a temperature in excess of 200°F at any rpm between idle and 100%.

4. The static pressure measured on the inside of the coupling in a plane through the rear of the fuselage shall never be greater than ambient nor more than 13 inches of water below ambient at any engine rpm.

5. No part of the assembly shall weigh more than 30,000 pounds, and each section shall be self supporting and joined together by conventional flanges and bolts. The external surfaces shall be suitably protected to prevent weather deterioration and injury to personnel from high temperature.

6. RAC will supply all airplane hold-down devices and templates, etc., to insure proper clearances to the airplane structure. Provisions shall be made to allow the airplane to move plus or minus 1-1/2 inches in any direction and synthetic foam rubber (cross section 4 x 4 inches minimum) shall also be provided where necessary. The forward end of the coupling structure shall be free to move plus or minus 1-1/2 inches vertically and laterally without benefit of the sponge rubber and the maximum total distributed load applied to the fuselage by the coupling shall not exceed 500 pounds.

Comments

1. RAC noise level readings indicate considerably more than 20 db attenuation in all octave bands above 75 cps as called for under design requirements.

2. Maximum fuselage temperatures at the coupling indicate only a 20°F rise over ambient at any rpm including shut-down.

3. Static pressure at 100% rpm is 9.0 inches water below ambient and is 0.4 inches water below ambient at idle (thus insuring correct airflow through the fuselage for ground cooling and scavenging of explosive vapors).

4. It should be noted that these mufflers were bought to alleviate the noise complaints from our neighborhood. No requirement was specified for intake silencers since operating personnel are required to use ear plugs.

5. RAC noise level readings taken at a distance of 100 feet in each octave band at angles of 45° aft, lateral and 45° forward indicate that, at no location or octave band, does the noise level exceed 100 db. This means that the installation is now well proportioned and that the installation is essentially non-directional.

Physical Characteristics of F/RF-84F Muffler Installation

NOTE: Applicable to Type B

1. I.A.C. Dura-Stack Model 2.5R3-10

2. RAC tracks and hold-down devices:
   P/N 37-38x8000-1 (A30A) (Patent applied for)

3. Operating instructions - Procedure M-2354

4. Dimensions

   a. Coupling 6 feet 2-3/8 inches long by 9 feet 2 inches diameter
   b. Augmenter 20 feet 0 inches long by 5 feet 0 inches I. D.
   c. Muffler 22 feet 0 inches long by 10 feet 7-1/2 inches I. D.
   d. Overall length including lagging 48 feet 7 inches (appr)
      Maximum height (at stack) 15 feet 5 inches
      Rear of fuselage 1 foot 8 inches ahead of flange joining coupling to augmenter

5. Miscellaneous dimensions and calculations:

   a. Secondary air radial opening 15.7 square feet
      Secondary air fin-rudder opening 1.6 square feet
      Total secondary air opening 17.3 square feet
   b. Net secondary area at rear of fuselage 11.25 square feet
   c. Exhaust stack opening 31.7 square feet
   d. Calculated engine airflow 114 pounds per second
   e. Calculated secondary airflow 132 pounds per second
   f. Augmentation ratio 1.16 to 1
   g. Calculated maximum secondary air inlet velocity 102 feet/second
      Calculated maximum stack exhaust velocity 96 feet/second
   h. Maximum stack temperature (measured at end of 15 minutes at 100% rpm) 600°F
   i. Stack temperature calculated from known engine. E.G.T., mass flow, ambient temperature and augmentation ratio 598°F
   j. Maximum temperature in muffler measured on muffler centerline 4 feet behind rear of augmenter 650°F